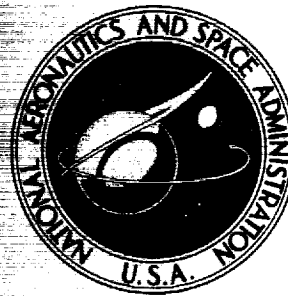


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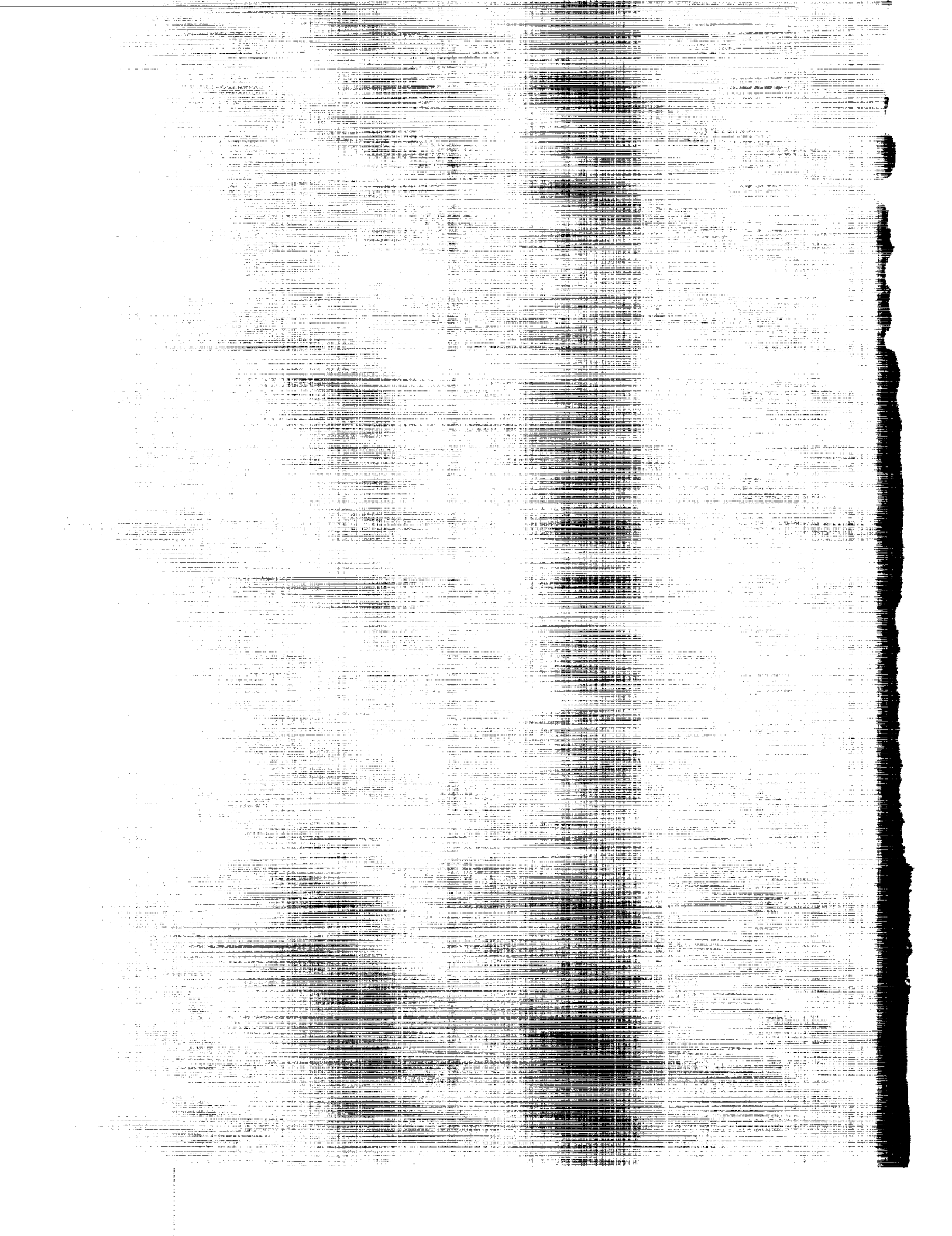
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**STUDY ON THE FEASIBILITY  
OF V/STOL CONCEPTS FOR  
SHORT HAUL TRANSPORT AIRCRAFT**

*Prepared by*  
**LOCKHEED-CALIFORNIA COMPANY**  
**Burbank, Calif.**  
*for Ames Research Center*

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1967**



**STUDY ON THE FEASIBILITY OF V/STOL CONCEPTS  
FOR SHORT HAUL TRANSPORT AIRCRAFT**

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**for Ames Research Center**

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## SUMMARY

The design, operational, and economic aspects of several different VTOL and STOL aircraft configurations were evaluated to determine which of the aircraft are most promising for development into successful commercial short haul transports. Aircraft were designed to carry 60 passengers for a distance of 500 statute miles, and other guidelines were established to assure that the vehicles would be studied on a common basis. The STOL aircraft included the deflected slipstream, jet flap, and fan-in wing configurations. The VTOL aircraft included tilt-wing, tilt-rotor, stopped-rotor and lift/cruise fan concepts.

Parametric and detail design studies were made to provide a basis for selecting the optimum design characteristics of each concept. Extensive use was made of computers to map vehicle weights, dimensions, performance, and direct operating costs as functions of the design parameters. The method used for calculating direct operating costs was based on the 1960 ATA method, with modifications appropriate for V/STOL operations. Several designs were selected from the initial data for further analysis, including development of 120 passenger configurations and more detailed design studies. The sensitivities of performance, weight, and cost to design changes and differences in mission rules were also examined. The basic characteristics of the final vehicles are shown in the following table.

### SUMMARY CHARACTERISTICS AND PERFORMANCE FOR FINAL CONFIGURATIONS

	Gross Weight (lb)	Cruise Speed (knots)	D.O.C.* cents/seat mile
60 PASSENGER			
Tilt Rotor VTOL	65,000.	363	2.67
Lift/Cruise Fan VTOL	71,800	474	2.87
Stopped Rotor VTOL	71,000	400	2.65
Deflected Slipstream STOL 2000-ft	46,900	283	1.96
Jet Flap STOL 2000-ft	63,200	483	2.26
Fan-in-Wing STOL 1000-ft	67,900	493	2.67
120 PASSENGER			
Tilt Rotor VTOL	123,500	390	2.01
Lift/Cruise Fan VTOL	141,600	480	2.36
Deflected Slipstream STOL 2000-ft	86,400	282	1.47
Jet Flap STOL 2000-ft	120,000	489	1.77
Fan-in-Wing STOL 1000-ft	124,000	498	2.04

\*) 500-mile stage length

A brief analysis of short haul transport operations in the New York and Los Angeles areas indicated that V/STOL aircraft can operate from downtown terminals using air-space not presently used by conventional aircraft and that vehicle concept, other than the effect on noise, is less critical to downtown operations than having area-type navigation and air traffic control systems.

Within the guidelines and scope of the study, on the basis of promise, it is concluded that the order of preference of the STOL concepts is: deflected slipstream, fan-in-wing, and jet-flap; of the V/STOL concepts the order is: stowed rotor, tilt rotor, lift/cruise fan, and tilt-wing.

The noise sensitivity analysis involved a study of the effects on noise, weight, and direct operating costs (DOC) of parametric changes to the aircraft. The parameters varied were tip speeds and thrust-to-weight ratio. To determine the effects on noise, a two point evaluation was selected, one for the aircraft in an on-ground condition, the other for a fly-over condition. The aircraft and engine performance data, at the two locations selected for the evaluation, were used to calculate the noise for each aircraft. The noise was evaluated in terms of perceived noise level (PNL), a measure of annoyance commonly used in aircraft work. The results show that PNdB near brake release is least for low disc loading concepts, and beyond 2000 feet the aircraft noise from fan-type concepts is the least.

To permit development of these concepts into successful short haul transports further general and specific research and development programs must be initiated. Specific research subjects for each vehicle concept are indicated in this report. The most important research subjects are (1) Noise prediction and reduction, (2) VTOL control and handling qualities (3) Aerodynamic interference for propeller and rotor vehicles with disc loading less than 25 lb/sq ft, (4) Airline simulation and demand, and (5) Control of multiple gas generators on a common manifold for fan and rotor vehicles.

## INTRODUCTION

Vertical and/or short takeoff and landing aircraft technology has advanced steadily over the past few years to where the feasibility of a large number of concepts has been demonstrated by wind tunnel model tests and/or "test bed" flight articles, while the need for VTOL or STOL commercial transports is gradually being recognized in both the airframe and airline industries and is evidenced by the many published papers on the subject. It is therefore timely to conduct a study to determine which of these various VTOL and STOL vehicle concepts are most suitable for use as commercial transports, both to establish economic feasibility and to define the residual research problems connected with the more desirable vehicles. The results will permit suitable research planning on the key problems of the most promising aircraft.

The study included initially seven basic types of aircraft, each designed for two field lengths (except the tilt wing) as follows:

<u>Vehicle Type</u>	<u>Field Length - takeoff and landing</u>
Turboprop STOL	1000 ft and 2000 ft
Turbofan STOL	1000 ft and 2000 ft
Fan-in-Wing STOL	1000 ft and 2000 ft
Tilt Wing V/STOL	0
Lift and Cruise Fan V/STOL	0 and 1000 ft
Stopped Rotor V/STOL	0 and 1000 ft
Tilt Prop Rotor V/STOL	0 and 1000 ft

All of these vehicles were designed to a prescribed set of guidelines and to a constant set of assumptions in order to assure comparisons on a common basis. A summary of the guidelines established by the NASA is included in Appendix A. Additional ground rules and invariants necessary to totally bound the designs in parametric terms are listed and discussed in the parametric section.

The purpose of this study was to conduct a comprehensive and careful comparison of a limited number of candidate VTOL and STOL concepts for a variety of operating conditions to determine which vehicles are the most promising for development into successful short-haul transports. In order to assure comparisons on a common basis, direct operating cost at a stage length of 500 statute miles was used as the primary figure of merit and each particular vehicle is optimized and sized for the design mission.

Although the initial scope of the vehicle optimization and design study included the above 13 aircraft, the concept development phase of the study together with the vehicle performance optimization parametric study resulted in examination of a significantly larger number of individual aircraft. The major steps are discussed in the Concept Development section. Following the concept development and optimization study several vehicles were selected for more detailed design, performance and cost sensitivity analyses. These latter studies in most cases served to identify areas for further improvement in vehicle performance, however, these improvements are not reflected in the final vehicle designs because the design and sensitivity studies were conducted concurrently toward the end of the study. The sensitivity analyses are used as a basis for justification of some of the recommended research programs. The data presented in this report is restricted to comparisons of the final vehicles, both 60 and 120 passenger. The sensitivity analyses are based on the parametric vehicle designs.

The study included an economic analysis phase that provided the basis for computation of direct operating costs at the design stage length and shorter stage lengths as well. In addition, a variety of other economic factors were investigated including effects of aircraft utilization, production quantity, and distribution of RDT&E costs. The effect of using the aircraft in a simplified airline route structure was also investigated to determine if there was agreement between the simplest and more complex figures of merit for vehicle comparisons.

An operational analysis was conducted to determine the feasibility of short haul VTOL and STOL aircraft operations in congested areas. The operational analysis included such factors as noise, service, safety, maintenance, air traffic control, etc., that provide a means together with cost data, of conducting a general assessment of the feasibility of the various vehicles to be used for commercial short haul transports.

The parametric, design, and economic studies provided a common numerical basis for comparison of vehicle concepts but this is only part of the relative evaluation of concepts. There are numerous qualitative factors that always must be considered in a general assessment

of feasibility and these include fail safety, service, maintenance, noise, and development risk. In addition, block speed is an important parameter in terms of passenger preference as well as its direct influence on direct operating cost. These quantitative and qualitative factors are combined to provide orders of preference for the STOL and VTOL vehicles. No direct comparison is made between STOL and VTOL vehicles.

A major aim of the study was to define the most important research problems for each of the vehicle concepts. Numerous research subjects were disclosed and there are a few that have application to almost all the vehicles, while others are unique to individual vehicles. Each research program is identified as specifically as possible within the space limitations of this summary report.

The studies conducted for NASA by three contractors have served to emphasize both the future potential service to the public of short haul V/STOL transports and the research required to realize this potential.

## SYMBOLS

A	disk area, ft <sup>2</sup>
AR	aspect ratio $\frac{b^2}{S}$
b	wing span, ft
B	number of blades
BLC	boundary layer control
C	rotor blade chord, ft
C <sub>d</sub>	drag coefficient
C <sub>f</sub>	skin friction coefficient
C <sub>nβ</sub>	static directional stability derivative
C <sub>μ</sub>	blowing momentum coefficient, $\frac{W_a V_i}{g q_\infty S_W}$
C <sub>T/σ</sub>	$\frac{T}{R \rho (\Omega R)^2 B C}$
D <sub>E</sub>	diameter engine nacelles, ft.
D <sub>f</sub>	diameter fuselage, ft

D.O.C.	direct operating cost, cents per seat mile
f	equivalent parasite drag area, ft <sup>2</sup>
F <sub>d</sub>	lift fan diameter, inches
g	gravitational constant, ft/sec <sup>2</sup>
h <sub>p</sub>	pressure altitude, feet
I <sub>x</sub>	roll inertia, slug ft <sup>2</sup>
I <sub>y</sub>	pitch inertia, slug ft <sup>2</sup>
I <sub>z</sub>	yaw inertia, slug ft <sup>2</sup>
L/D	lift to drag ratio
N <sub>β</sub>	$\frac{\rho S V^2}{2 I_z} \cdot b \cdot C_{n\beta} \left( \frac{1}{\text{sec}^2 \text{rad}} \right)$
N <sub>r</sub>	$\frac{\rho S C}{4 I_z} \cdot b^2 \cdot C_{nr} \left( \frac{1}{\text{sec-rad}} \right)$
P <sub>D</sub>	propeller diameter, ft
q <sub>∞</sub>	freestream dynamic pressure, lb/ft <sup>2</sup>
R	rotor radius, ft
S	wing area, ft <sup>2</sup>
S <sub>REF</sub>	reference wing area, ft <sup>2</sup>
S <sub>WET</sub>	wetted area, ft <sup>2</sup>
SFC	specific fuel consumption, lb/lb/hr
SHP	shaft horsepower
T or F <sub>n</sub>	thrust, lbs
T <sub>B</sub>	block time, hrs
T/W	thrust to weight ratio
t/c	wing thickness ratio
U	forward velocity, ft/sec
V <sub>app</sub>	approach speed, knots

$V_B$	block speed, mph
$V_C$	cruise speed, knots
$V_D$	design dive speed, knots
$V_i$	jet velocity, ft/sec
$V_{LDG}$	landing speed, knots
$V_S$	stall speed, knots
$V_T$	rotor/propeller tip speed, ft/sec
$V_{TO}$	takeoff speed, knots
$W_a$	jet nozzle airflow, lb/sec
$W_f$	fuel weight, lb
$W_{fb}$	block fuel, lb
$W_G$	gross weight, lb
$W/A$	disk loading lb/ft <sup>2</sup>
$W/S$	wing loading, lb/ft <sup>2</sup>
$\Delta C_{dc}$	compressibility drag coefficient
$\Delta C_{dp}$	parasite drag coefficient
$\Delta L_i$	incremental fan induced lift, lb
$\eta_p$	propeller efficiency
$\gamma$	glide path angle, degrees
$\Lambda$	wing sweep, degrees
$\lambda$	taper ratio
$\Omega$	rotor rotational speed, rad/sec
$\omega$	frequency, cycles per second
$\ddot{\phi}$	roll acceleration, rad/sec <sup>2</sup>
$\ddot{\psi}$	yaw acceleration, rad/sec <sup>2</sup>
$\rho$	air density
$\ddot{\theta}$	pitch acceleration, rad/sec <sup>2</sup>

## DESIGN STUDY METHOD

### Approach

The study approach and logic is defined on the flow diagram on Figure 1. In addition to the study basic ground rules established by NASA and summarized in Appendix A, general and specific parametric study invariants and general rules were then established to ensure that each concept was performed and costed on an equal basis and that the final design iteration from the selected parametric aircraft would require the smallest possible design change.

The next step defined the study variables matrix for each aircraft, and constraints to the study matrix were imposed. "Stick" figures (three-view sketches) of both propulsion and aircraft geometry established the necessity for elimination of some of the more extreme geometric combinations of aircraft dimensions, propeller diameter, location of power plants, etc. Another constraint was imposed by conducting a cruise-D.O.C. sensitivity analysis which indicated that high wing loadings are desirable for minimum D.O.C.; hence, only medium and high wing loadings were considered for the complete parametric study. Best judgement selections were made of the geometric variables which combined to produce minimum D.O.C. aircraft, and point designs were drawn for each aircraft concept which permitted estimation of propulsion system losses, fuselage wetted area, control and stabilizing surface sizing, flaps system, etc. At this point, the acceptable parametric aircraft were performed through a parametric computer program to define vehicle weight, performance, and D.O.C.

From the 13 initial designs parametrically analyzed, 5 design point aircraft were selected for further refinements. For these final studies, the configuration and propulsion system of the Jet Flap STOL and the Lift/Cruise Fan VTOL designs were significantly changed to improve the design characteristics and to reduce weight and D.O.C.

### Parametric Study

Computer Programs. - Eleven computer programs were developed and interfaced to permit uninterrupted evaluation of each parametric aircraft from the initial phase of defining the aircraft geometry to the final costing of the aircraft.

The initial program, titled A/C geometry, shown in Figure 2, defined the geometry,

thrust loading, gross weight, and other pertinent details of the aircraft. This information then flows into two major channels:

The Weight Program to describe the component weight breakdown for costing purposes and to determine fuel available for the aircraft to perform the mission

The Drag Build Up Program to describe the minimum drag level based on total wetted area, the parasite drag based on wing airfoil characteristics, the induced drag based on aspect ratio, the compressibility drag as a function of wing aspect ratio, sweep angle, and thickness ratio

If the aircraft employs a turbofan or turbojet propulsion system, the flow of data begins at the Engine Sizing Program where control requirements and system losses are accounted for, then enters the Engine Data Program where the engine characteristics are defined and thence to the Mission Program as thrust and SFC versus speed and altitude. For turboprop aircraft, the propeller characteristics are defined in the Propeller Equation Program, then described as efficiency and shaft horsepower between the Propeller Efficiency Program and Engine Data Program, then combined to define the propulsion system characteristics in terms of thrust in the Propeller Thrust Program and thence to thrust and fuel flow in performing the aircraft through the Missions Programs. At this point sufficient information is available to perform each aircraft over the prescribed mission. Several aircraft were weighed and performed to obtain a cross-plot of fuel available and fuel required for the fixed 500 statute mile stage length, to provide the exact characteristics of the aircraft at a fuel-available/fuel-required ratio of one. An example of the computer-plotted output is shown on Figure 3. This aircraft is then introduced to the Cost Program to provide direct operating cost.

Invariants and Ground Rules. - The invariants and ground rules employed are listed on Figure 4. Some are discussed in further detail in the following paragraphs.

Drag and Performance. - Total drag is defined as

$$C_{D \text{ Total}} = C_f \frac{S_{\text{wet}}}{S_{\text{ref}}} + \Delta C_{D_p} + \frac{C_L^2}{\pi AR} + \Delta C_{D_c} + \Delta C_{D_o}$$

To justify the skin friction levels, existing flight data is correlated as a function of aircraft wetted area. From these correlations, levels of  $C_f$  have been selected as 0.0035

for turboprop aircraft and 0.0032 for turbofan aircraft. Parasite drag, or drag due to nonelliptical loading, is defined as essentially due to wing. The parasite drag variation with lift coefficient was established and the induced drag defined as  $C_L^2 / \pi AR$ , with  $e = 1.0$ . Compressibility drag, defined by a Mach divergence technique is a function of  $t/c$ ,  $AR$ , and Sweep.

Mission Profile. - The design flight profile is shown in detail on Figure 5.

Stability and Control. - Stability and control requirements were stipulated based on the guideline requirements. For the VTOL aircraft, at  $V = 0$ , obtaining the required level of control and  $T/W$  required programming the equations for stability and control into the engine sizing program to determine for each parametric aircraft the most critical requirements, and sizing the engine accordingly. Vertical tail surfaces for the VTOL aircraft are sized for a  $C_{n\beta}^{Fus} + C_{n\beta}^{Vert Tail} = 0.0015$  per/deg. Horizontal tails are sized for sufficient control to trim to a  $C_{L Max} = 2.0$  with flaps at  $30^\circ$  and a static margin of 5%.

For the STOL aircraft sizing of control and stabilizing surfaces is more difficult. Control and stability requirements are provided by the lightest and most effective control surface. Tail areas are determined in the parametric study for both the longitudinal and directional requirements as a function of gross weight and/or inertia for the 1000 foot and 2000 foot field length conditions. The larger requirement for tail surface area, as governed by either stability or control, is used. The gross weight inertia correlations for the roll, pitch, and yaw axes based on numerous existing aircraft were used in the study. A more detailed breakdown of inertia for the remaining study concepts is presented in the Addendum report. Following the selection of the most promising V/STOL concepts a final iteration on control methods and tail surfaces was made.

It should be emphasized that initial sizing of the parametric aircraft stipulated the full level of control (100%) required by the study ground rules. The effects of reducing these control requirements are noted in the following sections for several specific aircraft.

Side Studies. - Numerous side studies were made to verify the design rules, establish boundaries for the matrix of study variables, and insure that parametric aircraft meet the study requirements. Detailed information is available on the following topics in the Short Haul Addendum Report LR 19585. The volume number follows each topic.

Inertia Correlation	Vol. II	Tilt Rotor Blade Dynamic Studies	Vol. II
Wing t/c Limitation	Vol. II	Propeller Efficiency	Vol. II
Stall Margin Limitation	Vol. II	Tail Areas-Control Requirements	Vol. II
Jet Flap $C_L$ vs. $C_\mu$	Vol. II	Fan-in-Wing Induced Lift	Vol. II
3-view Sketches	Vol. I	Component Weights	Vol. III
Minimum DOC A/C Geometry	Vol. III	Propulsion System Diagrams	Vol. III

Two aerodynamic studies were pursued to ensure the validity of the fan-in-wing and jet flap aircraft designs. The first study defined the induced incremental lift attainable on the fan-in-wing concepts due to fan thrust and included an evaluation of the correlation between theoretical results and experimental data. The second study determined the circulation lift versus blowing momentum coefficient for the jet flap airplanes, within the range of aspect ratios studied.

Detailed studies for evaluation of propeller efficiency versus blade angle of attack at various values of L/D and helix angle were conducted for the tilt rotor concept to ensure attainment of relatively high propeller efficiencies at high speed for low disc loadings.

To verify achievement of the required 10-knot stall margin on the deflected slipstream airplane, a typical high lift system was selected from NASA TN-D55 and evaluated for the 1000 foot STOL. The results indicated that a fast acting flap system would be required to attain the stall margin desired over the wing loading range to be investigated. The settings on approach would vary from  $50^\circ/50^\circ$  ( $50^\circ$  on first and  $50^\circ$  on the second segment) to  $30^\circ/30^\circ$ . Later studies indicated that for the 2000 foot STOL, flap complexity can be reduced; a slotted Fowler can provide the desired field length and stall margin.

Propulsion studies were conducted to determine the best procedures for matching engine RPM with propeller tip speed to ensure good takeoff performance and optimum cruise capability. Two-speed propeller reduction gearboxes can be eliminated, at only small penalties in shaft horsepower and specific fuel consumption, by the use of a variable speed free turbine.

Since resonant blade frequencies are of major concern during the stopping mode of flight on the stopped rotor concept, a detailed frequency analysis was undertaken to insure that the various chordwise and flapping frequencies would be sufficiently separated to preclude blade dynamic problems.

Complete component weight equations were defined and programmed for each aircraft concept. Direct Operating Cost equations were written for each concept, programmed, and interfaced between the weight and mission programs to permit accurate and rapid determination of D.O.C. These equations are described in detail in the Addendum Report, LR 19585.

Study Variables. - The matrix of parametric study variables is identified on Figure 6A. The combinations of study variables represent those parametric aircraft initially performed through the computer programs. Review of these results indicated areas of improvement in the original design concepts which would result in improved performance, lower gross weight and hence lower D.O.C. aircraft. These improvements were incorporated into the final selected aircraft on a point design basis, however, and were not rerun through the complete parametric program. The resulting improved concepts are noted on Figure 4 as items 2. Numerous sensitivity studies were also conducted on the point designs to determine for each specific concept those design variables which most significantly affect the overall D.O.C. An additional parametric study was performed to further refine the tilt rotor and stopped rotor vehicles. The matrix of parametric variables considered for this additional study is shown in Figure 6B.

### Design Development

Each vehicle concept was the subject of a brief morphological study in which the major configuration and propulsion variables were arranged in all possible combinations. The multitude of resulting vehicles was examined for compliance with commercial requirements and, on a judgement basis, the most suitable were selected for the design and parametric studies. The resulting vehicles were generalized in terms of wing loading, aspect ratio, disc loading, etc., as indicated in the discussion of the parametric study. Concurrently, point vehicle designs were developed to support and justify the inputs to the parametric study. The general chronology of the primary design development during the study is shown on Figure 7. Each type of vehicle and the changes during its development that are indicated schematically on Figure 7 will be discussed in the following paragraphs. Each of these vehicles was sized and optimized for 60 passengers and a range of 500 statute miles.

The STOL aircraft listed first include the jet-flap turbojet, fan-in-wing, and deflected slipstream. First on the list, the turbofan STOL configuration development, considered several configurations of the turbofan deflected slipstream and the supercirculation jet-flap concepts, each in conjunction with appropriate form of control systems for longitudinal trim and glide path control. Because of stringent STOL requirements, the turbofan STOL immediately developed into a jet-flap configuration. The jet-flap concept initially evolved as a turbojet aircraft with engines located close to the fuselage and manifolded to the trailing

edge nozzles to provide high  $C_\mu$  and high circulation lift. Tail surfaces were provided with blowing BLC, and a download on the large horizontal tail was used for pitch-trim control. This vehicle weighed about 90,000 pounds for a 1000-foot field, and the evaluation suggested that some method of glide-path control was required to offset the large thrust component from blowing. The evaluation also indicated that turbofan engines, with the fan flow directed downward at the flaps, would provide a more efficient vehicle. Jets were located forward underneath the fuselage to control pitch trim and glide path. The parametric programs resulted in a minimum DOC aircraft weighing 82,600 pounds that was obviously unacceptable.

Comparison with other optimized vehicles from the parametric study showed the jet-flap 1000-foot STOL to be excessively heavy with relatively high D.O.C. in addition to having some undesirable design characteristics. The jet-flap configuration was then redesigned to operate from a 2000-foot FAA field length, which resulted in lower  $C_\mu$  requirements and the elimination of pitch control jet nozzles in the nose of the airplane. The revised configuration includes vectoring exhaust nozzles for both the engine fan and primary gas flows. The turbofan engines were also moved further outboard to reduce drag.

The major variable connected with the development of the fan-in-wing STOL configuration were the number and arrangement of fans, and the method of control. To vary fan diameters logically as required in the parametric study and to minimize the wing weights resulting from incorporating fans into the wing structure, a fixed ratio of fan diameter to wing chord and fixed chordwise location of the fans was specified for the outboard fan. The number of fans was selected as 4, after consideration of an 8-fan design, and the method of control, after numerous iterations, was selected as reaction type about all axes. This concept remained essentially unchanged throughout the study, and the final design was optimized for the 1000-foot field length.

Further studies conducted later in the program indicated improvement in D.O.C. for higher values of  $C_{Lmax}$ , suggesting that the use of small blowing type flaps could lead to a more optimum vehicle. The 8-fan-in-wing configuration, previously eliminated during the early part of the design development and parametric study mainly because of its complexity, could therefore merit further evaluation.

Configuration development of the turboprop STOL was naturally limited to the deflected slipstream concept and consisted mainly of studies to select the flap geometry appropriate

for a chosen field length. Various flap geometries were evaluated in terms of glide path and stall margin capability. For the parametric study the rather complicated double segment slotted flap based on NASA TN D-55 was selected for both the 1000 foot and 2000 foot STOL. The 1000 foot STOL optimized through the parametric study weighed 50,600 pounds. At the second review the 2000 foot STOL was selected for further evaluation; hence the flap system was re-evaluated and simplified to a single segment slotted Fowler flap.

Configuration development of the VTOL concepts presented on Figure 7 follows steps similar to the evolution of the STOL vehicles.

The original lift/cruise fan concept shown schematically in the first column, "concept development," features two lift fans located at a fixed position of each side of the fuselage ahead of the wings and two tiltable cruise fans in conventional pods on the aft fuselage. The forward louvered lift fans retract into the fuselage ahead of the passenger compartment in conventional flight. Reaction control is used about all three axes. Development of this concept essentially entailed selection of lift and cruise fan locations.

The safety and maintainability of this configuration were not considered satisfactory because of the location of the engines and extensive hot gas ducting above the passenger compartment. In addition, the airplane was comparatively heavy due to fuel requirements at high power for approach and go-around time. Further study to devise means of reducing the gross weight, improving safety and maintenance and reducing fuel weight requirements resulted in a revised configuration shown schematically in the third column "final design." This latter version is characterized by two wing tip propulsion pods. Each pod incorporates three gas generators driving a cruise fan and lift fan. The number of gas generators was increased from 4 to 6 to realize a better match between cruise power and one-engine-out VTOL power requirements. Both the cruise fan nozzles and lift fan louvers are vectored to control lift, roll, and transition. These improvements reduced the takeoff gross weight to 71,800 pounds.

The basic tilt-wing turboprop concept evolved into two separate concepts because of a desire to consider a range of disk loadings from 10 to 100 pounds per square foot. The extreme wing size that results from using light disk loadings with four non-overlapped propellers produced the tilt-rotor family as a subcategory of the tilt-wing family. Both types of configurations were included in the optimization program with the result that the lightest and lowest cost four-propeller tilt wing had a gross weight of 73,000 pounds while the

corresponding tilt rotor vehicle had a lighter gross weight and a lower direct operating cost. The tilt-wing vehicle was therefore eliminated since it was not sufficiently competitive. The tilt-rotor configuration was considered representative of the original vehicle concept and all further work was concentrated on the twin-rotor configuration.

Various rotor and forward propulsion systems were evaluated during the development of the last vehicle, the stopped rotor VTOL configuration. The configuration selected for the parametric study incorporated a single folding rotor to allow low disk loadings and incorporated a tail pusher propeller for conventional flight.

The propulsion system consists of four turboshaft engines driving the pusher propeller, the main rotor and anti-torque tail rotor through individual overrunning clutches. The rotors are each connected to the system by a clutch and brake which are operated when the rotor system is unloaded and the main rotor folded for cruise operations.

The final configuration shown in the third column incorporates several improvements. The forward propulsion system was revised to include two conventionally wing-mounted propellers and engine pods since the pusher propeller diameter became excessively large for the heavier vehicles. The relocation of the four engines from a cluster installation on top of the passenger compartment close to the main rotor shaft to wing mounted pods significantly improves the vehicle safety and reduces maintenance. In addition, the rotor is folded and retracted down onto the top of the fuselage to minimize drag in cruising flight. The final design for the 60-passenger aircraft resulted in a take-off gross weight of 71,000 pounds.

The best stopped-rotor vehicle has a small wing, like the other VTOL vehicles and has a disk loading of 13 pounds per square foot. The blades have an optimized taper in planform, percent thickness, and in spar tube wall thickness. Transition drag considerations determine the size of the propellers for this vehicle; consequently, there are few variables to be optimized. The optimization was relatively flat in terms of disk loading in that values as high as 15 pounds per square foot could have been used with little increase in direct operating cost.

## DESIGN STUDY RESULTS

The iterative processes previously described were used to optimize and evaluate the thirteen initial vehicle concepts and select the final aircraft for more detailed design, performance and cost sensitivity analyses. The selected vehicles which include two VTOL concepts: the tilt-rotor and lift/cruise fan, and three STOL concepts: the deflected slipstream 2000 foot, jet-flap 2000 foot, and fan-in-wing 1000 foot, were developed for two sizes, 60 and 120 passenger, and reflect more detailed stability and control analyses and a refinement of weight data. A 60-passenger, stopped rotor VTOL is also included for comparison. In addition to a description of the main design features of each vehicle and a presentation of their comparative characteristics and performance, the results of various sensitivity studies are included in this section. These sensitivity studies were conducted on the final parametric vehicles and permitted definition of areas for further improvement in vehicle performance. These improvements were not incorporated into the design of the final aircraft since the latter preceded the results from the sensitivity studies.

The physical characteristics of the final configurations are presented on Figure 8 for the 60-passenger versions and Figure 9 for the 120-passenger versions. (The Fan-In-Wing T/W is based on turbo-jet thrust.) Figure 10 presents the performance of both 60 and 120 passenger final aircraft for the 500 statute mile range mission. A breakdown of segment fuel in pounds for the same basic mission is tabulated on Figure 11 for all final vehicles.

A discussion and comparative evaluation of these results is presented in the conclusion section.

### Common Design Features

For the same passenger capacity, the basic fuselage configuration is common to all concepts. The fuselages are designed to meet the study requirements for crew, passenger, baggage, and revenue cargo accommodations. Since thin-backed seats are used, their 32-inch pitch is equivalent to a conventional seat at 34-inch pitch. The five-abreast seating for the 60-passenger airplanes and the six-abreast seating for the 120-passenger airplanes were found to afford the best compromise between weight, aerodynamic drag, center of gravity shift, and compartment utility.

Some of the vehicle basic concepts imposed a high wing configuration. Where a se-

lection was possible, a high wing and wing mounted engine nacelles were chosen to minimize aerodynamic ground interference effects, foreign object damage and reingestion.

The basic landing gear design is the result of a combination fuselage-landing gear weight optimization study reported in the Addendum to this report. Since all configurations are high-wing airplanes, the main gear is mounted to the fuselage and retracts beneath the passenger floor.

#### Deflected Slipstream STOL 2000-ft

General Description - The general arrangements of the 60- and 120-passenger 2000-foot STOL deflected slipstream are shown in Figures 12 and 13 and the propulsion system diagram in Figure 14.

The aircraft are high, cantilever winged monoplanes with four interconnected four-bladed propellers driven by four scaled versions of the GE1/S1 turboshaft engines. The wing span is established at the minimum dimension that would be entirely within the slipstream and provide suitable clearances between propellers and fuselage. The propeller tip speed is limited to 900 ft/sec at takeoff RPM and the propeller cruise RPM at 0.705 take-off RPM. A NACA 64A series airfoil is used with a wing thickness ratio of 0.15 at the root and 0.13 at the tip. The  $0^\circ$  sweepback wing has a taper ratio and aspect ratio of 0.7 and 6, respectively.

Full span, constant chord, Fowler flaps, similar to those used on the Lockheed Electra, are utilized. The location of the propellers relative to the wing was chosen after examination of reference 5 and applicable references listed in Volume II of the Addendum Report LR 19585.

The aircraft utilizes 50 percent chord elevators and a movable stabilizer interconnected to the flap for pitch control and trim, and a 40 percent chord rudder with boundary layer control using air bleed from the engine compressors for yaw control. Constant chord full span wing spoilers are used differentially for roll control.

Conventional air conditioning, electrical and electronics, retractable landing gear, hydraulic systems and dual cable full powered flight controls are used.

Electric generators and hydraulic pumps are run mechanically on the accessory sec-

tion of each engine. An auxiliary power unit is installed to provide pneumatic and electrical power while the aircraft is on the ground.

The weight statement of the 60- and 120-passenger deflected slipstream is shown in Figure 15. In order to limit the center of gravity travel from 18.5 to 31.5% MAC, some passenger seat restriction is necessary when the number of passengers is less than 45 and 50, respectively.

The calculated mass moment of inertia properties of these configurations are as follows:

	<u>60-passenger</u>	<u>120-passenger</u>
Roll - $I_{xx}$ (slug-feet <sup>2</sup> )	$0.285 \times 10^6$	$0.80 \times 10^6$
Pitch - $I_{yy}$ (slug-feet <sup>2</sup> )	$0.345 \times 10^6$	$1.21 \times 10^6$
Yaw - $I_{zz}$ (slug-feet <sup>2</sup> )	$0.592 \times 10^6$	$1.90 \times 10^6$

Stability and control: Control of the deflected slipstream is obtained with a boundary layer control rudder, conventional elevator, and lift spoilers for roll control. This is a simple and reliable arrangement which retains the basically unsophisticated character of the airplane.

Figure 16 summarizes the control power capabilities and stability characteristics. Sideslip rate damping is required to provide satisfactory low speed handling qualities.

The airport performance is noted as follows:

	Takeoff Distance	Landing Distance	T.O. Climb Grad. One Engine Out		LDG. Climb Grad. One Engine Out
			1st Seg	2nd Seg	
60 pass	1336 ft	980 ft	17.8%	14.4%	17.5%
120 pass	1777 ft	980 ft	14.4%	12.9%	14.4%
Req'd	2000 ft	2000 ft	0.5% @ $V_{LO}$	1.7% @ $1.2 V_s$	3.2% @ $1.3 V_s$

Trade-off and sensitivity studies. - These studies utilized the parametric aircraft as a basis since the aircraft designs were being finalized concurrently toward the end of the study. The aircraft sensitivity to engine SHP, in terms of gross weight, block speed, and D.O.C. is shown in the following table.

**DEFLECTED SLIPSTREAM STOL - SENSITIVITY OF GROSS WEIGHT,  
BLOCK SPEED, AND D.O.C. TO FLAT RATED INSTALLED HORSEPOWER**

60 Passenger - 500-Statute-Mile Range

Rated Horsepower	SHP of Selected Basic Configuration	SHP/W <sub>G</sub> 1.50 X Basic	SHP/W <sub>G</sub> 2.0 X Basic
Gross Weight, lb	45,600 (100%)	48,600 (106.6%)	51,800 (113.6%)
Block Speed, knots	244 (100%)	273 (111.9%)	278.6 (114.2%)
D.O.C., cents	1.92 (100%)	1.90 (99%)	2.02 (105.2%)

The installed engine-power to gross-weight ratio is increased to 1.5 and 2 times the parametric vehicle level, without changing the takeoff power to gross weight ratio and propeller geometry. This revision does not significantly change the takeoff performance or the transmission and gearbox weights, but provides higher power for cruise and some other flight conditions.

Results show that a small gain in D.O.C. can be obtained by increasing the engine installed power (flat rated). For a small increase in power the appreciable improvement in both cruise and block speeds more than compensates for the higher vehicle gross weight and fuel cost. Larger increases in power do not provide equivalent speed advantage because the propellers cannot absorb the additional power efficiently. The improvement in block speed is not sufficient to compensate for the larger gross weight, resulting in higher D.O.C. Because of the form of the D.O.C. equation, the vehicle gross weight becomes a more important factor at lower block speed. It is probable that further propeller optimization could lead to better D.O.C. values at the higher power levels. The higher speeds could contribute significantly to the preference of passengers for this concept.

It is interesting to note the agreement between the table below and Figure C-9. The table shows a decrease in D.O.C. with an increase in block speed up to a point around 270 to 275 knots and then an increase in D.O.C. from that point on. The trend is the same in the results shown in C-9 except that the block speed did not go above the region in which the minimum occurs.

The aircraft sensitivity to flap chord/wing chord ratio, in terms of gross weight, block speed, and D.O.C. is presented in the following table:

DEFLECTED SLIPSTREAM STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO FLAP CHORD/WING CHORD RATIO  
60 Passenger - 500-Statute-Mile Range

Flap Chord/Wing Chord	20% Chord	30% Chord	40% Chord	50% Chord
Gross Weight, lb	44,200 (96.9%)	44,700 (98%)	45,600 (100%)	47,100 (103.3%)
Block Speed, knots	243.1 (96.6%)	243.5 (99.8%)	244 (100%)	244.6 (100.3%)
D.O.C., cents	1.88 (97.9%)	1.89 (98.4%)	1.92 (100%)	1.97 (102.6%)

The vehicle gross weight was calculated for each flap chord to wing chord ratio, maintaining the lift coefficient constant. The block speed shows negligible variation and the increase in D.O.C. results mainly from the adverse effect due to a larger gross weight. It appears from the results that the use of sophisticated flap systems should improve D.O.C. without increasing or possibly even reducing flap chord.

The aircraft sensitivity to field length, in terms of gross weight, block speed and D.O.C. is shown in the following table.

DEFLECTED SLIPSTREAM STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO FIELD LENGTH

60 Passenger - 500-Statute-Mile Range

Field Length	Field Length 1000 ft	Field Length 1400 ft	Field Length 2000ft
Gross Weight, lb	50,600 (100%)	48,000 (94.9%)	45,600 (90.1%)
Block Speed, knots	278.3 (100%)	251.3 (90.3%)	244 (87.7%)
D.O.C., cents	1.94 (100%)	1.98 (102%)	1.92 (99%)

The lower gross weight and block speed have an opposite effect on D.O.C. Because of lower engine power requirements for takeoff, the vehicles designed for 1400 feet and 2000 feet field length cruise at slower speeds. The reduction in block speed is particularly significant between 1000-foot and 1400-foot field length. Although the gross weight reduction due to longer field length is an important factor in the D.O.C. equation, for a slow vehicle, the 27 knots reduction in block speed brings the D.O.C. up to 1.98 cents. From 1400 feet to 2000 feet the adverse effect due to a smaller reduction in speed is more than compensated by the smaller vehicle gross weight.

The aircraft sensitivity to skin friction coefficient ( $C_f$ ), in terms of gross weight, block speed, and D.O.C. appears in the following table:

DEFLECTED SLIPSTREAM STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO SKIN FRICTION COEFFICIENT  $C_f$

60 Passenger - 500-Statute-Mile Range

Skin Friction Coef. $C_f$	$C_f = .0025$	$C_f = .0035$	$C_f = .0045$
Gross Weight, lb	44,900 (98.5%)	45,600 (100%)	46,320 (101.6%)
Block Speed, knots	262.6 (107.6%)	244 (100%)	230 (94.3%)
D.O.C., cents	1.77 (92.2%)	1.92 (100%)	2.05 (106.8%)

As would be expected both the gross weight and block speed are adversely affected by larger coefficient of friction, resulting in higher D.O.C. The  $\frac{SHP}{W}$  and field length were maintained constant.

The aircraft sensitivity to tail size, in terms of gross weight, block speed, and D.O.C., are presented in the following table:

DEFLECTED SLIPSTREAM STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO TAIL SIZE  
60 Passenger - 500-Statute-Mile Range

Tail Area Factor	.75 Tail Area Factor	1.0 Tail Area Factor	1.5 Tail Area Factor	2.0 Tail Area Factor
Gross Weight, lb	45,350 (99.5%)	45,600 (100%)	46,100 (101.1%)	46,500 (102.1%)
Block Speed, knots	243.9 (99.9%)	244 (100%)	244.2 (100.1%)	244.4 (100.2%)
D.O.C., cents	1.91 (99.5%)	1.92 (100%)	1.93 (100.5%)	1.95 (101.6%)

The variation in tail size, representative of the control requirements, has no practical effect on the vehicle block speed and only limited impact on the vehicle gross weight and D.O.C., since the tail represents only a small fraction of the total cost.

The effect of the removal of the cross shafting on the gross weight was determined for the three designs described in the field length sensitivity study. Each of these designs sized for 1000-, 1400-, and 2000-ft field length was re-weighted to account for the removal of the cross shafting. The elimination of the cross shafting reduces the thrust and lift on the engine-out side, resulting in higher rotation speed and longer field length. With the original power plants operating at 110 percent of the normal takeoff power, the asymmetric moment due to the differential thrust was entirely compensated at the new rotation speed by increasing the size of the vertical tail. The vehicle was then re-weighted and performed

to determine the new field length. The data shown on Figure 17 indicate that for a fixed gross weight the removal of cross shafting leads to longer field lengths, however, this penalty becomes less significant for lower vehicle gross weight. For a given length, removal of the cross shafting increases the thrust-to-weight ratio requirement, and therefore the vehicle gross weight. Takeoff is the critical case, since the landing field length of all designs considered is equal to or less than that for takeoff at the design gross weight; take-off power exceeds approach power and lift-off speed is less than approach speed.

Figure 17 shows that the use of cross shafting provides a lighter weight design up to field lengths of at least 3000 feet. Hence, for STOL designs the variation of design complexity with field length is confined to the flaps. The 1000 foot STOL design incorporates a 50 percent chord complicated double segment flap. The 2000 foot final selected design uses a 40 percent chord single segment flap. No attempt has been made to determine the exact point between 1000 and 2000 feet at which the change in flap design is desirable. As discussed elsewhere, the TND-55 flap used in the 1000 foot design requires rapid acting flaps and large angle of attack changes to meet the 10 knot horizontal gust approach case.

The aircraft sensitivity to number of passengers, in terms of gross weight, block speed and D.O.C., is shown in the following table:

DEFLECTED SLIPSTREAM STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO NUMBER OF PASSENGERS  
60 Passenger - 500-Statute-Mile Range

NUMBER OF PASSENGERS	60-Passenger	120-Passenger
Gross Weight, lb	45,600 (100%)	86,500 (189.7%)
Block Speed, knots	244 (100%)	242.2 (99.3%)
D.O.C., cents	1.92 (100%)	1.47 (76.%)

## Jet Flap STOL 2000 - ft

General description. - The general arrangements of the 60- and 120-passenger jet flap STOL are shown on Figures 18 and 19 and a propulsion diagram on Figure 20.

The wing planform has a  $25^\circ$  sweep angle at the quarter chord line and a taper ratio of 0.4. A jet flap system providing circulation lift augmentation is used on the full span flaps ( $C_\mu = 0.2$ ), rudder, and elevator. A leading edge slat is also included.

The blowing flow is provided by the exhaust gas of the four scaled GE1/DF9 type 1.1 bypass ratio turbofan engines. The fan flow exhausts through two vectoring nozzles similar to the Bristol Siddeley Pegasus nozzle at the front of the nacelle. The gas generator exhaust duct contains two Pegasus type vectoring nozzles and an aft nozzle. A diverter valve in the duct to the latter nozzle permits diversion of one-half of the primary gas flow from each engine to a wing manifold. One duct in the wing is in the leading edge of the flap and aileron; the other between the flap and aileron leading edge and the wing rear beam. A crossover duct in the center fuselage connects with a single duct running aft for tail surface blowing.

It should be noted that the parametric optimization of the jet flap STOL vehicle is based on a 1.1 to 1 engine bypass ratio for lack of suitable data on other engines at the time of the parametric study, and hence does not represent a fully optimized configuration.

In order to maintain a constant nozzle area one-fourth of the gas generator primary output is bled off overboard through two gas jettison valves on the aft fuselage duct when all engines are operative. In the event of engine failure, the failed engine is isolated by operating its diverter valve and the jettison valves are closed so that the blowing gas flow in the jet flap system remains unchanged. With the jet flap system turned off the four turbofans operate conventionally.

The vectoring fan and primary gas nozzles provide cruise thrust, vertical thrust for takeoff, and reverse thrust for descent and landing.

Conventional construction is used throughout the aircraft except for the gas ducts and nozzle efflux areas. For these parts high temperature steel and titanium are used.

The final design weights statement of the 2000-ft STOL jet flap concept for both 60- and 120-passenger configurations are presented in Figure 21. The center of gravity travel is limited to a most forward and aft position corresponding to 18.5 and 31.5% M.A.C. by restricting the use of the two most forward seat rows when the number of passengers is less than 30 for the 60 passenger version, and the two most forward and two most aft rows when the number of passengers is less than 76 for the 120 passenger aircraft.

The calculated mass moment of inertia properties of these configurations are as follows

	60-passenger	120-passenger
Roll - $I_{xx}$ (slug-feet <sup>2</sup> )	$0.401 \times 10^6$	$1.35 \times 10^6$
Pitch - $I_{yy}$ (slug-feet <sup>2</sup> )	$0.445 \times 10^6$	$1.41 \times 10^6$
Yaw - $I_{zz}$ (slug-feet <sup>2</sup> )	$0.797 \times 10^6$	$2.59 \times 10^6$

Stability and control: The control system for the jet flap airplane is obtained with conventional rudder and elevator which incorporates a high level of boundary layer control, plus differential deflection of jet flapped ailerons. The ailerons are deflected from a drooped - position which corresponds to the position of the inboard jet flaps. One-half the primary engine air is bled into a system of ducts which supply the jet flap and tail boundary layer control system. One-half the bleed air is supplied to the wing jet flap, one-quarter is used for the tail boundary layer control system, and one-quarter is jettisoned overboard. When an engine fails, both the overboard jettison and the inoperative engine are closed off from the system.

The primary gas which is not bled off is ejected through Pegasus type rotating cascade nozzles. The front fan air is ejected through similar nozzles. The fan and primary exhaust cascades are used jointly for lift augmentation, pitch trim and glide path control.

Takeoff and landing are both at approximately 86 knots. Takeoff flap setting is 45 degrees; landing flap setting is 60 degrees. The landing configuration is thus subject to a higher degree of flaps-down blowing effects than is the takeoff configuration.

Figure 22 summarizes the control powers and estimated levels of the major stability terms for an 86 knot landing approach.

Preliminary studies of jet blowing effects on stability, which form part of this study are described in the Addendum Report. The basic concept relates the stability characteristics of a jet flapped wing to those of an unblown wing whose geometry is transformed in terms of momentum coefficient and flap deflection. Definition of these effects and the general type of stability augmentation needed can be made only after further study and experimental work. However, artificial sideslip rate damping is definitely required to produce satisfactory low speed flying qualities.

The airport performance is as follows:

	Takeoff Distance	Landing Distance	T. O. Climb Grad. One Engine Out		LDG. Climb Grad. One Engine Out
			1st Seg.	2nd Seg.	
60-passenger	2000 ft	2000 ft	14.6%	19.3%	14.6%
120-passenger	2000 ft	2000 ft	14.2%	17.7%	14.4%
Required	2000 ft	2000 ft	0.5%	1.7%	3.2%
			@V <sub>LO</sub>	@1.2V <sub>s</sub>	@1.3V <sub>s</sub>

Trade-off and sensitivity studies. - These studies utilize the parametric aircraft as a basis since the aircraft designs were being finalized concurrently toward the end of the study. The aircraft sensitivity to number of passengers, in terms of gross weight, block speed, and D.O.C. is shown in the following table.

JET FLAP STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO NUMBER OF PASSENGERS  
500-Statute-Mile Range

Number of Passengers	60-Passenger		120-Passenger	
Gross Weight, lb	59,500	(100%)	114,300	(192.1%)
Block Speed, knots	368.1	(100%)	368.9	(100.2%)
D.O.C. cents	2.18	(100%)	1.71	(78.4%)

The following table shows the aircraft sensitivity to engine bypass ratio, in terms of gross weight, block speed, and D.O.C.

JET FLAP STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO BYPASS RATIO  
60 Passengers - 500-Statute-Mile Range

By-Pass Ratio	By-Pass Ratio 1.1 to 1		By-Pass Ratio 2 to 1		By-Pass Ratio 6 to 1	
Gross Weight, lb	59,500	(100%)	56,700	( 95.3%)	53,000	(89.1%)
Block Speed, knots	368.1	(100%)	380	(103.2%)	356	(96.7%)
D.O.C. cents	2.18	(100%)	2.03	( 93.1%)	2.06	(94.5%)

The engine thrust-to-weight ratio is constant and an engine compressor pressure ratio of 13 to 1 was used with the 1.1 to 1 and 6 to 1 by-pass ratios. Because the appropriate engine data was not available in time an engine compressor pressure ratio of 30 to 1 was used for the 2 to 1 turbofan by-pass ratio, so that the results shown for this by-pass ratio are not directly comparable to the other two conditions.

The larger by-pass ratios improve S.F.C. and appreciably reduce the vehicle gross weight and overall fuel costs. The small reduction in block speed is not sufficient to negate the D.O.C. gain provided by the weight and fuel savings. Thus it can be concluded that future jet flap STOL short haul transports should use by-pass ratios above 2.0 and probably as high as 6.0.

Fan-in-Wing STOL 1000-ft

General Description. - The general arrangement of the 60- and 120-passenger Fan-in-Wing aircraft are shown in Figures 23 and 24 and the propulsion system diagram for both vehicles is shown in Figure 25.

The fuselage is of conventional skin, stringer, and frame construction. The wing is a conventional two-spar torque box except at the lift fan positions where wing torsion is reacted by differential bending between the wing spars. T-tails were chosen to reduce destabilization on the horizontal tail due to downwash. The horizontal tails have variable incidence for longitudinal trim. A NACA 64A series airfoil is used with a wing thickness ratio of 0.13 at the inboard fan and 0.12 at the outboard fan. A constant wing sweep of 25° at the quarter chord line was used.

The propulsion system consists of four scaled GE1/J1 gas generators which are used in the normal manner for cruise flight, and are diverted to drive GE variable stator area tip turbine lift fans for takeoff and landing. The lift fans are cross ducted to maintain symmetrical fan lift in case of an engine failure. Semi-circular divided doors close the fans on the wing upper surface and louvers are used on the lower surface. A constant fan pressure ratio of 1.3 was selected, based on previous studies which indicated that this pressure ratio provides close to the lightest weight for the propulsion system and fuel for the portion of the mission for which the fans were used.

When a gas generator fails it is shut off from the system by the diverter valve and the total gas generator exit area is reduced by one-quarter by partial closure of the tip turbine and reaction control jet nozzles.

Reaction jets at the wing tips and in the fuselage tail, to augment aerodynamic control force in low speed flight, are manifolded into the fan duct system.

Takeoff and initial climb are made using vectored fan thrust from all four fans up to a speed of about 120 knots EAS when the gas generator flow is diverted to the cruise nozzles and the fan doors and vectoring vanes are closed. The landing sequencing is the reverse of that used for takeoff.

The final design weight statements of the STOL Fan-in-Wing for both 60- and 120-passenger configurations are presented in Figure 26. The center of gravity travel is limited to a most forward and aft position corresponding to 18.5% and 31.5% MAC by restricting the use of the two last seat rows when the number of passengers is less than 30 for the 60-passenger version, and the two forward and aft seat rows when the total number of passengers is less than 82 for the 120-passenger aircraft.

The calculated mass moment of inertia properties of these configurations are as follows:

	60-passenger	120-passenger
Roll - $I_{xx}$ (slug-feet <sup>2</sup> )	$0.331 \times 10^6$	$1.03 \times 10^6$
Pitch - $I_{yy}$ (slug-feet <sup>2</sup> )	$0.554 \times 10^6$	$1.58 \times 10^6$
Yaw - $I_{zz}$ (slug-feet <sup>2</sup> )	$0.787 \times 10^6$	$2.42 \times 10^6$

Control of the Fan-in-Wing vehicle is maintained by conventional aerodynamic controls plus reaction jets about all three axes. It is considered that the selected control system and associated empennage size is a reasonable compromise which does not unduly penalize the propulsion system or cruise flight characteristics. The control system is felt to be the most reliable system that could be chosen due to the severe control that the Fan-in-Wing demands. It is felt that the greater weight associated with this type of control system is justified by reliability.

The 50-knot approach condition represents the lowest normal operating speed and is therefore critical for both control and stability. The control powers, summarized in Figure 27, are considered adequate at the 50-knot approach speed with all engines operative. At least 75 percent of this control power is available after a single gas generator failure.

Stability and damping are very similar for both 60- and 120-passenger designs. Figure 28 summarizes the levels of stability and damping for a maximum gross weight landing approach at 50 knots.

Sideslip rate damping and yaw/sideslip stability augmentation is considered sufficient to provide reasonable handling qualities. The airport performance is as follows:

	Takeoff Distance	Landing Distance	T.O. Climb Grad. One Engine Out		LDG. Climb. Grad. One Engine Out
			1st Seg.	2nd Seg.	
60 passengers	921 ft	890 ft	12.3%	22.9%	23%
120 passengers	945 ft	890 ft	8.5%	13.9%	14%
Req'd	1000 ft	1000 ft	0.5%@ $V_{Lo}$	1.7%@ $1.2V_s$	3.2%@ $1.3V_s$

Trade-off and sensitivity studies. - These studies utilize the parametric aircraft as a basis since the aircraft designs were being finalized concurrently toward the end of the study. The aircraft sensitivity to number of passengers in terms of the gross weight, block speed, and D.O.C., is shown in the following table.

FAN-IN-WING STOL — SENSITIVITY OF GROSS WEIGHT,  
BLOCK SPEED, AND D.O.C. TO NUMBER OF PASSENGERS  
500-Statute-Mile Range

Number of Passengers	60 Passenger		120 Passenger	
Gross Weight, lb	63,700	(100%)	117,400	(182.6%)
Block Speed, knots	382	(100%)	385.4	(100.9%)
D.O.C., cents	2.54	(100%)	1.96	( 77.2%)

The aircraft sensitivity to cruise speed, in terms of gross weight, block speed, and D.O.C. is presented in the following table.

FAN-IN-WING STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO CRUISE SPEED  
60 Passenger - 500-Statute-Mile Range

Cruise Speed	Cruise Speed M = .65	Cruise Speed M = .7	Cruise Speed M = .75	Cruise Speed M = .8	Cruise Speed M = .835
Gross Weight - lb	55,400 (87.0%)	56,400 (88.5%)	57,500 (90.3%)	59,800 (93.8%)	63,700 (100%)
Block Speed - knots	313 (81.9%)	332 (86.9%)	354 (92.7%)	370 (96.8%)	382 (100%)
D.O.C., - cents	2.51 (98.8%)	2.44 (96.1%)	2.37 (93.3%)	2.40 (94.5%)	2.54 (100%)

The minimum D.O.C. corresponds to a cruise speed of Mach 0.75 and a block speed of 354 knots.

The aircraft sensitivity to maximum lift coefficient, in terms of gross weight, block speed and D.O.C. is shown in the following table:

FAN-IN-WING STOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO  $C_{Lmax}$

60 Passenger - 500-Statute-Mile Range

$C_{Lmax}$	$C_{Lmax}$ .9 Design	$C_{Lmax}$ .95 Design	$C_{Lmax}$ Design	$C_{Lmax}$ 1.05 Design	$C_{Lmax}$ 1.10 Design
Gross Weight - lb	73,200 (101.2%)	72,800 (100.7%)	72,300 (100%)	71,000 (98.2%)	69,200 (95.7%)
Block Speed - knots	403.9 (100.4%)	403.4 (100.3%)	402.2 (100%)	400.6 (99.6%)	399.4 (99.3%)
D.O.C. - cents	2.57 (101.1%)	2.55 (100.4%)	2.54 (100%)	2.49 (98.0%)	2.44 (96.1%)

Raising the  $C_{L_{max}}$  10% above the selected value improves the D.O.C. by 3.9%. This gain suggests that the use of small blowing type flaps could possibly lead to lower D.O.C., and that the 8 fan-in-wing configuration previously eliminated during the early part of the parametric study because of its complexity, merits further evaluation. This study is based on the original parametric design and did not include a revision of flap weight as function of lift coefficient, however, the vehicle gross weight was adjusted to reflect the effect of  $C_{L_{max}}$  on the overall design.

### Tilt-Rotor VTOL

Introduction. - Empty weight in a helicopter is of such great importance that every possible means of reducing weight is and must be explored if VTOL attributes are to be expanded and exploited. One recognized approach to weight reduction is increasing rotor tip speed which results in lower weight rotors and main transmissions. Higher tip speeds, however, increase profile drag losses with a resulting loss in figure of merit. Since figure of merit is the ratio of thrust power developed for hover to the shaft horsepower required to produce this thrust, a lowering of the rotor figure of merit requires an increase in engine size which tends to offset any weight reduction in the transmission and rotor.

The question posed, therefore, is how to increase rotor tip speed without loss of figure of merit? Extensive aircraft propeller research and development over the past years has faced the same question and has found one answer: reduce profile drag by reducing airfoil section thickness at the high speed tip portions of the blade. Such an approach to rotary wing appears to be a fruitful effort.

Figure 29 is an indication of improvements in figure of merit which can be attained by application of propeller technology to rotor blade design. The lower curve shows the variation of figure of merit with tip speed for a representative rotor using rotor blade design representative of today's practice; nominal tip thickness to chord ratios of 12%, solidity of 0.1, thrust coefficient to solidity ratio ( $C_T/\sigma$ ) of 0.1, and washout angle of 8 degrees. This data was obtained from the Lockheed Rotor Performance Computer Program. The upper curve was cross checked by using both a rotor performance program and a propeller performance program.

The approximate figure of merit being measured on propellers used on the tilt-wing C-142B is also plotted in Figure 29 which indicates a figure of merit equal to 0.79 (from unpublished data) at an operating tip speed of 900 feet per second. This propeller has a solidity of 0.17,  $C_T/\sigma$  of 0.13, washout twist of 43 degrees, and thickness ratio at the tip of 0.033. The thickness at the hub is in the order of 35% chord which shows a high taper in thickness.

Analytical work has shown that the upper curve of Figure 29 labeled "propeller technology", is attainable for rotors by going to the high thickness taper -- or at least to low thickness ratio at the rotor blade tip. Note that an approximate correction for solidity from 0.17 for the propeller to 0.1 for a rotor blade in the expression:

$$\text{Figure of merit} = \frac{C_T^{3/2}/\sqrt{2}}{\frac{C_T^{3/2}}{\sqrt{2}} + \frac{\sigma \delta_m}{8}}$$

shows that the figure of merit would drop from 0.79 to 0.69.

It is recognized that the maximum lift coefficient of the rotor blade is reduced when the thickness-to-chord ratio is reduced. This would adversely affect figure of merit. Thus it will be necessary to introduce airfoil camber to regain the loss of maximum lift coefficient, as is the case in propeller technology.

The rotor weight variation associated with rotor versus propeller technology is due primarily to planform taper, thickness taper, and twist angle. The planform taper and thickness taper tend to make the blade lighter since the blade geometric distribution and load distribution may be matched. However, the rotor hub may be heavier due to higher stiffness requirements. The high twist angle required for the tilt rotor also adversely affects the rotor weight. Preliminary studies indicate that there is a 2 percent penalty to rotor weights on the stopped rotor going from rotor to propeller technology and a 4 percent penalty on the tilt rotor vehicles. The difference is due to the difference in twist angle of the blades. It should be pointed out, however, that rotor weights are lighter for the higher tip speeds since the solidity ratio may be reduced as tip speed is increased.

Vehicle Comparison. - The tilt rotor aircraft was selected by considering a matrix of 27 configurations, consisting of all the combinations of three gross weights, three rotor diameters, and three rotor tip speeds. The rotors for these configurations were held to a constant  $C_T/\sigma$  of 0.1; the blades had propeller-like high taper in thickness; and a blade twist angle of  $24.72^\circ$  was chosen, which was considered to be near optimum from previous trade-off studies (Volume II of Addendum Report). Each combination of the above variables defines a unique disc loading and rotor solidity. These in turn define engine size, activity factor, and rotor figure of merit. For each of these rotors a map of efficiency in forward flight was calculated using a digital computer program. All of these configurations were then run on

a computer mission analysis program to provide D.O.C. 's from which a minimum D.O.C. aircraft was selected. Figure 30 shows the characteristics of the final selected tilt-rotor configuration resulting from the parametric study in the column headed Rotor Technology. This figure shows that the minimum D.O.C. airplane based on present rotor technology has a rotor figure of merit of 0.621 at a tip speed of 800 feet per second. Additional development of rotors with high thickness taper ratios would significantly raise the figure of merit at the higher tip speeds as discussed in the Recommended Research and Development section of this report. The column labeled Propeller Technology presents a minimum D.O.C. aircraft based on a higher figure of merit. The optimum aircraft now has a rotor tip speed of 900 feet per second corresponding to a rotor figure of merit of 0.69 and a solidity ratio of .086.

Vehicle Description. - The general arrangements of the 60- and 120-passenger tilt-rotor VTOL are shown on Figures 31 and 32 respectively. The cross shafted propulsion system shown schematically on Figure 33 consists of four GE1/S1A type turboshaft engines mounted in pairs at each wing tip and driving two large prop-rotors through individual overrunning clutches. The rotors are interconnected across the wing by a high-speed shaft system which is used to supply equal power to each rotor during normal and emergency operation and to ensure rotor synchronization. The shaft is sized to accept one-half the torque output of one engine, thereby allowing equal power distribution to the rotors during three engine operation. The rotor cross-shafting is also used to drive the hydraulic pumps, the electrical generators, and the compressors of the air conditioning system located near the centerline of the airplane. Engine starting is provided by hydraulic power supplied by an APU located in the fuselage. Airplane and rotor anti-icing is electrical.

The engine nacelles are located on each wing tip and the wing span is the minimum compatible with suitable propeller-fuselage clearance. The nacelles are rotated by the action of high ratio harmonic drive gear trains anchored to the pivot shaft attach fitting and wing closure section. Its output ring gear is attached to the nacelle rotation torque input frames. The harmonic drive is actuated by two hydraulic motors, powered by separate hydraulic systems, either of which has the necessary power to rotate one nacelle. The motors are servo controlled and further synchronization is assured by a nacelle rotation interconnecting cross-shaft with the capability of transmitting power between nacelles. On the ground, the engine nacelles must be positioned 48 degrees above a horizontal position in order to provide the necessary rotor clearance with the ground.

The leading edge of the wing contains the functional systems such as hydraulics, electrical, fuel, and fire extinguishing lines and engine and rotor controls. Rotor and nacelle rotation cross-shafting is contained in the wing bay between the 15- and 35-percent chord spars. Fuel is contained in the wing between the 35- and 60-percent chord spars, outboard of the fuselage. Deflection of flaps and ailerons reduces the hover power requirements by relieving the wing down-load and improves the lift capability for transition.

In the helicopter mode, control in the roll, pitch, and yaw axes is provided respectively by differential collective pitch control and cyclic pitch control. Conventional control surfaces are used in the airplane mode and are coupled with the rotor control gyros to "coordinate" rotor and airframe motions. The vehicle design is based on the following constants: maximum rotor tip speed of 900 feet/second, wing taper ratio of 0.6, and a NACA 64 series airfoil with a wing thickness ratio of 0.16 at the root and 0.14 at the tip.

The nacelle is of conventional sheet metal, stringer, bulkhead, and frame construction. The forward section is designed as a torsion box to take rotor and engine torque plus the nacelle rotation drive forces. The transmission oil cooler is located in the forward portion of the nacelle. The aft section is designed with removable fairing to provide complete access to the engines, controls, and nacelle rotation power hinge.

The rotor control and power transmission system consists of a planetary gear box, control gyro, collective pitch servo, and cyclic pitch controls. Wiring, fuel lines, and hydraulic lines are routed through the pivot shaft. Collective and cyclic pitch controls and propeller cross-shafting are also routed through the pivot shaft and are located on the shaft centerline.

The transmission design differs substantially in general arrangement from those normally used for rotor drive systems. Instead of mounting the rotor on a rotating shaft, the rotor hub is mounted directly on bearings on a nonrotating shaft which projects from the forward top end of the transmission.

This concept allows utilization of a "pogo-stick" type rotor flight control installation inside of the hollow nonrotating rotor support shaft. The integral control gyro and swash-plate are located above the rotor hub on a nonrotating antifriction bearing gimbal. The nonrotating "pogo-stick" extends through the support shaft and the cyclic control input forces are supplied from the aft and lower side of the transmission.

Collective pitch control is achieved by vertical or linear movement of the entire gyro, gimbal, pogo-stick, and cyclic system by action of the collective pitch servo. Cyclic pitch controls are not affected by the action due to a ball spline on its input torque tube which precludes coupling between cyclic and collective pitch.

The transmission itself basically consists of an overrunning clutch provided at each engine input, combined with a gear shift system, operated by dual electro hydraulic valves.

The gearbox has an overall ratio of 47 to 1 for the hovering mode and 60 to 1, for the cruise mode. Cooling is provided by a dual stage oil cooler equipped with a variable exit nozzle for oil temperature control. An over-running clutch is provided at each engine input so that operative engines will not waste power turning a dead engine, and to further provide for gear shifting of each engine independently.

A small net weight saving is achieved by elimination of the gearshift, since the variable power turbine may be operated throughout the speed range. The weight subtracted by the elimination of gearshift mechanisms and controls more than offsets the weight increase required by slightly decreased power turbine efficiency. In addition, simplicity and reliability are greatly enhanced.

The final design weight statements of the VTOL Tilt Rotor concept for both 60- and 120-passenger configurations are presented in Figure 34. The center of gravity travel is limited to a most forward and aft position corresponding to 18.5% and 31.5% MAC by restricting the use of forward and aft seat rows for both vehicle sizes.

The calculated mass moment of inertia properties of these configurations are as follows:

	<u>60-passenger</u>	<u>120-passenger</u>
Roll - $I_{xx}$ (slug-feet <sup>2</sup> )	$0.749 \times 10^6$	$2.55 \times 10^6$
Pitch - $I_{yy}$ (slug-feet <sup>2</sup> )	$0.481 \times 10^6$	$1.69 \times 10^6$
Yaw - $I_{zz}$ (slug-feet <sup>2</sup> )	$1.10 \times 10^6$	$3.81 \times 10^6$

Stability and Control: Stability and control investigations for the tilt rotor aircraft have been directed in the main toward the resolution of the feasibility of operation of large rotor/propellers both in hover and forward flight.

In the hover mode of flight, control is obtained solely from the rotors, i.e., cyclic for pitch, differential collective for roll, and differential cyclic for directional control. The final design is marginal in meeting the required VTOL directional and pitch control accelerations, and studies were conducted to determine means of increasing pitch and yaw control power. The desired control levels can be obtained by reducing  $C_{T/\sigma}$  of the rotor/prop from 0.12 to some lesser value. Sensitivity studies indicated that reductions in  $C_{T/\sigma}$  to approximately .10 result in negligible changes in D.O.C., hence the final tilt rotor selected design would be essentially unchanged by the increased control capability.

During transition flight, when rotors are tilting from vertical to horizontal, a mixing of controls is required. No detailed analysis of control has been undertaken at this condition; however, flight experience on a similar aircraft has shown that transition can occur at fairly low power levels and tilt angles, approximately 30 degrees, indicating essentially no loss in hover control capabilities.

The conventional longitudinal stability and control surfaces are sized to obtain a 5 percent static margin plus the requirement to trim at transition to a  $C_L = 2.0$  with 30 degree flap setting. An additional tail sizing consideration is imposed from the destabilizing contribution of rotor/prop normal force. The vertical tail surface is sized to obtain a  $C_{n\beta}$  level of 0.0015.

Trade-off and sensitivity studies. - These studies utilize the parametric aircraft as a basis since the aircraft designs were being finalized concurrently toward the end of the study. The aircraft sensitivity to number of passengers, in terms of gross weight, block speed, and D.O.C. is presented in the following table.

TILT ROTOR VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO NUMBER OF PASSENGERS  
500-Statute-Mile Range

Number of Passengers	60-Passenger	120-Passenger
Gross Weight, lb	58,200 (100%)	107,400 (186.7%)
Block Speed, knots	313 (100%)	326.5 (104.7%)
D.O.C., cents	2.27 (100%)	1.65 ( 72.7%)

Although the other vehicles show very little improvement in cruise and block speeds between the 60 and 120 passenger aircraft (Figure 10) the tilt rotor features a gain of 13.5 Knots and 29 Knots in block and cruise speeds respectively for the larger size aircraft.

The aircraft sensitivity to rotor weight in terms of gross weight, block speed, and D.O.C. is shown in the following table.

TILT ROTOR VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO ROTOR WEIGHT  
500-Statute-Mile Range

Rotor Weight	75% Basic Weight	100% Basic Weight	125% Basic Weight
Gross Weight, lb	56,250 (96.6%)	58,200 (100%)	60,400 (103.8%)
Block Speeds, knots	311.5 (99.5%)	313 (100%)	315.2 (100.7%)
D.O.C., cents	2.26 (99.6%)	2.27 (100%)	2.32 (102.2%)

The D.O.C. is not significantly affected by a change in rotor weight. The gross weight changes show larger percentage variations, but it is not a strong factor in the cost equation especially when combined with the high block speeds.

The aircraft sensitivity to installed power, flat rated for takeoff, in terms of gross weight, block speed, and D.O.C., is shown in the following table.

TILT ROTOR VTOL  
 SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
 AND D.O.C. TO FLAT RATED INSTALLED HORSEPOWER  
 500 Statute Mile Range

Engine Shaft Horsepower (Flat Rated)	100% Basic Engine SHP/W <sub>G</sub>	150% Basic Engine SHP/W <sub>G</sub>	200% Basic Engine SHP/W <sub>G</sub>
Gross Weight, Lbs.	58,200 (100%)	65,200 (112 %)	72,200 (124 %)
Block Speed, Knots	313 (100%)	341.4 (109 %)	345.6 (110.4%)
D.O.C., Cents	2.27 (100%)	2.42 (106.6%)	2.71 (119.4%)

The basic engine power-to-gross-weight ratio is increased to 1.5 and 2 times the parametric vehicle level, without changing the takeoff power to gross weight ratio. The additional power is supplied to the propellers for cruise and some other flight conditions, without significantly affecting transmission and gearbox weight. The block speed rises rapidly at first, but this effect is more than compensated by a 12% increase in gross weight due mainly to higher fuel weight increments, which is an important costing factor. The increase in power is accompanied by a lowering in propeller efficiency, and higher S.F.C. In this higher speed range the drag rise begins also to affect the fuel weight requirement.

Although higher speeds do not correspond to optimum D.O.C. values, an airline could possibly consider the improvement in schedule time to be an overriding consideration.

The aircraft sensitivity to stage length, in terms of block speed and D.O.C. is presented in the following table.

TILT ROTOR VTOL  
 SENSITIVITY OF BLOCK SPEED  
 AND D.O.C. TO STAGE LENGTH

Stage Length Statute Miles	25	50	100	200	500
Block Speed, Knots	95.1 (30.4%)	150.6 (48.0%)	220.8 (70.5%)	281.2 (89.8%)	313.3 (100%)
D.O.C., Cents	9.42 (415.0%)	5.71 (251.5%)	3.76 (165.6%)	2.79 (122.9%)	2.27 (100%)

The study ground rule is to maintain a constant empty weight and adjust the gross weight as a function of the fuel requirement for the particular stage length. The adverse effect of short stage length on both block speed and D.O.C. are obvious.

The aircraft sensitivity to rotor blade drag coefficient ( $C_{D_o}$ ) in terms of gross weight, block speed, and D.O.C. is presented in the following table. With taper in thickness, the basic  $C_{D_o}$  varies from blade tip to root .004 to .033, respectively. The incremental change in  $C_{D_o}$  was introduced at each station along the span.

TILT ROTOR VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO  $C_{D_o}$  OF ROTOR BLADE  
500 Statute Mile Range

$C_{D_o}$ (Rotor Blades)	Basic $C_{D_o} - .001$	Basic $C_{D_o}$	Basic $C_{D_o} + .001$
Gross Weight, lb	57,950	58,200	58,550
Block Speed, knots	311	313	316
D.O.C., cents	2.27 (100%)	2.27 (100%)	2.27 (100%)

The D.O.C. is insensitive to rotor blade drag coefficient ( $C_{D_o}$ ) over the range of values investigated for this configuration. A higher value of the drag coefficient reduces the rotor figure of merit and increases the shaft horsepower requirements. The slightly higher block speed resulting from the additional installed power is compensated by a small variation in gross weight.

Lift/Cruise Fan VTOL

General description. - The final 60- and 120-passenger lift/cruise fan VTOL designs, shown in Figures 35 and 36 respectively, are high wing T-tail airplanes of conventional construction. The T-tail configuration is used to minimize the destabilization due to downwash.

Each wing tip pod contains three scaled GE1/J1 type gas generators, a G. E. type variable stator tip turbine driven lift fan, and a cruise fan driven by a four-stage turbine. These units are hung from the main wing beam structure extension in the pod.

The propulsion system schematic is shown on Figure 37. The center gas generator uses a cruise air intake and supplies gas primarily to drive the cruise fan turbine. The two side generators employ air intakes on the sides of the pod and are used primarily to drive the lift fan. All three gas generators discharge through isolation valves into a common manifold so that in the event of gas generator failure it is isolated from the system and essentially symmetric lift is obtained. The lift fans are equipped with shutoff valves and a shutoff valve at each wing tip pod prevents pressurization of the gas supply duct to the pitch and yaw control valve during conventional flight. The cruise fan discharges through vectoring nozzles similar to the Bristol Siddeley Pegasus nozzle. The lift fan is equipped with intake doors and vectoring exit louvers.

The wing sweep is 25 degrees at the quarter chord and conventional simple slotted flaps and sealed ailerons are used. The NACA 64A series airfoil has a thickness ratio of 0.13 at the root and 0.10 at the tip. The wing has an aspect ratio of 3 and a taper ratio of 0.4.

For roll control, lift is spoiled by vectoring the cruise fan nozzle aft and the lift fan louvers forward on one wing tip pod and unspoiling lift on the other pod by reverse movement of the nozzle and louvers. For lift control, lift is changed by vectoring the cruise fan nozzles and the lift fan louvers in opposite directions in unison on both pods. During transition the cruise fan nozzles and the lift fans' louvers are vectored in the same direction in unison on both pods. During conventional flight the cruise fan nozzles are vectored straight aft and the lift fans' inlet doors and exit louvers are closed.

The pitch and yaw control nozzle, located at the aft extremity of the fuselage, is a turret type double spool valve. Rotation of the outer spool provides pitch, yaw, or any combination of pitch and yaw forces. The thrust for pitch and yaw is controlled by rotation of the inner spool of the valve, which controls the size of the nozzles. All of the thrust vectoring devices are designed to provide full control in less than two-tenths of one second. Control during conventional flight is attained by conventional flap, aileron, rudder, and variable incidence horizontal tail.

Airframe construction is conventional except for the ducts and control nozzle which are fabricated of high temperature steel. An APU is installed so that the aircraft is self sufficient. All hydraulics, pneumatics, electrical and air conditioning systems are of conventional design.

The weight statements for the 60- and 120-passenger aircraft are presented in Figure 38. The center of gravity travel varies from 18.5% to 28.5% MAC for both airplanes, well within the desired limits of 18.5% to 31.5% MAC. There is practically no seat restriction required for these aircraft.

The calculated mass moment of inertia properties of these configurations are as follows:

	<u>60-passenger</u>	<u>120-passenger</u>
Roll - $I_{xx}$ (slug-feet <sup>2</sup> )	$0.382 \times 10^6$	$1.39 \times 10^6$
Pitch - $I_{yy}$ (slug-feet <sup>2</sup> )	$0.518 \times 10^6$	$1.83 \times 10^6$
Yaw - $I_{zz}$ (slug-feet <sup>2</sup> )	$0.847 \times 10^6$	$3.15 \times 10^6$

Stability and control: Pitch and yaw control are obtained in the hover mode by jet thrust nozzles located in the aft fuselage extremity. During hover maximum fan thrust is maintained and the latter is deflected so that the lift component is about 15 percent less than the total thrust. Roll control is obtained by reducing the fan thrust deflection on one side and deflecting more on the other side, without change in the total lift. At higher speeds the control power is augmented by conventional aerodynamic controls.

The control powers are summarized below for hover at maximum gross weight for the 60-passenger design. These control powers are reduced to 80% for the 120-passenger design.

All engines operative, trimmed about 0.25 MAC:

$$\frac{T}{W} = 1.15 \quad \begin{array}{l} \text{No roll control available.} \\ 0.6 \text{ rad/sec}^2 \text{ in pitch or } 0.5 \text{ rad/sec}^2 \text{ in yaw.} \end{array}$$

$$\frac{T}{W} = 1.0 \quad \begin{array}{l} 0.6 \text{ rad/sec}^2 \text{ in roll and} \\ 0.6 \text{ rad/sec}^2 \text{ in pitch or } 0.5 \text{ rad/sec}^2 \text{ in yaw.} \end{array}$$

One gas generator inoperative, trimmed about 0.25 MAC:

$$\frac{T}{W} = 1.15 \quad \begin{array}{l} \text{No roll control available} \\ 0.12 \text{ rad/sec}^2 \text{ in pitch and} \\ 0.10 \text{ rad/sec}^2 \text{ in yaw.} \end{array}$$

$$\frac{T}{W} = 1.0 \quad \begin{array}{l} 0.6 \text{ rad/sec}^2 \text{ in roll and} \\ 0.12 \text{ rad/sec}^2 \text{ in pitch and} \\ 0.10 \text{ rad/sec}^2 \text{ in yaw.} \end{array}$$

All desired levels of control power appropriate to a single engine failure are met. In normal six-gas generator operation, both pitch and yaw requirements are met, but the roll control power is less than desired. Maximum roll control power for the 60-passenger design is  $0.6 \text{ rad/sec}^2$  at  $T/W = 1.0$ ; about  $2/3$  of this value is available at  $T/W = 1.05$ . This is less than  $1.2 \text{ rad/sec}^2$  desired at  $T/W = 1.0$  and  $0.60 \text{ rad/sec}^2$  desired at  $T/W = 1.05$ .

Takeoff transition is accomplished by deflecting both the lift fan louvers and the cruise fan nozzles to an aft position. At zero forward velocity the vertical forces are balanced at  $T/W = 1.0$  and a pitching moment balance is maintained. Pitching moments arising from lift fan thrust fall off and fan inlet air momentum moments are trimmed throughout the entire transition by the pitch control reaction jet and with elevator. At 200 knots four gas generators and the lift fans are shut off and flight continues with one gas generator driving each cruise fan.

Landing transition is initiated from the same condition at which takeoff transition is terminated. Inoperative engines are restarted and diverted into the lift fans and control system, vanes and cascades are rotated forward for braking, and a vertical force balance is maintained. At low speeds additional braking is realized by trimming to a slight nose up attitude. At  $V = 0$  the cascade and vanes are rotated rapidly to the hover position. Figures 39 and 40 show lapsed time and distance covered for takeoff transition to 200 knots and for landing transition started from 200 knots.

This vehicle requires a complete 6 degree of freedom autopilot stability augmentation system.

Trade-off and sensitivity studies. - These studies utilize the parametric aircraft as a basis since the aircraft designs were being finalized concurrently toward the end of the study. The aircraft sensitivity to number of passengers, in terms of gross weight, block speed, and D.O.C. is shown in the following table.

LIFT/CRUISE FAN VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C TO NUMBER OF PASSENGERS  
500 Statute Mile Range

Number of Passengers	60 Passenger		120 Passenger	
Gross Weight, lb	70,000	(100%)	142,000	(202.9%)
Block Speed, knots	355.0	(100%)	355.0	(100%)
D.O.C., cents	2.82	(100%)	2.37	(84%)

The sensitivity of the aircraft to number of gas generators in terms of gross weight, block speed, and D.O.C. is shown in the following table

LIFT/CRUISE FAN VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO NUMBER OF GAS GENERATORS  
500 Statute Mile Range

Number of Gas Generators	4		6		8	
Gross Weight, lb	72,400	(103.4%)	70,000	(100%)	67,600	(96.6%)
Block Speed, knots	374	(105.1%)	355.8	(100%)	334	(93.9%)
D O.C , cents	2.85	(101.1%)	2.82	(100%)	2.82	(100%)

In order to minimize the penalty resulting from the drag rise these vehicles cruise on two engines only. It can be seen that the D O C. is generally insensitive to the number of engines and there is no variation between the 6 and 8 gas generator configurations.

For a constant thrust-to-weight ratio, the individual power plant size is inversely proportional to the number of engines. Since all vehicles cruise on two engines only, the smaller engines operate at a more optimum power setting resulting in lower SFC and total fuel weight. In addition, the minimum installed power requirement is determined by the takeoff with one engine failed condition. Since the failure of one engine represents a smaller percentage of the total installed power for the 6 and 8 engine configurations, a lower takeoff power level is required for these vehicles. These two factors reduce the air-

craft gross weight as the number of engines is increased from 4 to 8. The 6 and 8 gas generator vehicles have a lower cruising speed, however, because of the lower thrust available from 2 smaller engines. This reduction in block speed almost compensates the improvement in gross weight, resulting in small overall D.O.C. variations.

An evaluation of the results indicates that an 8-engine configuration, cruising on four engines to achieve a higher block speed without affecting appreciably the SFC and fuel fraction, is probably a more optimum vehicle in terms of D.O.C.

A similar conclusion would apply to the 120 passenger Lift/Cruise Fan VTOL. However, the heavier vehicle is characterized by a lower propulsion system weight-fraction. The percentage weight reduction which can be expected from the installation of a large number of engines is therefore somewhat smaller than that achieved with the 60 passenger vehicle. The block speed remains nevertheless a major factor in the cost equation and it can be expected that for a 120 passenger aircraft, the 8 engine configuration using 4 engines for cruise would be most efficient in terms of D.O.C.

The aircraft sensitivity to skin friction coefficient ( $C_f$ ), in terms of gross weight, block speed, and D.O.C. is presented in the following table:

LIFT/CRUISE FAN VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO SKIN FRICTION COEFFICIENT ( $C_f$ )  
500 Statute Mile Range - T/W Constant

Skin Friction Coef. $C_f$	$C_f$ .0025	$C_f$ .0032	$C_f$ .0045
Gross Weight, lb	68,500 (97.9%)	70,000 (100%)	73,200 (104.6%)
Block Speed, knots	350 (98.4%)	355.8 (100%)	337.6 (94.8%)
D.O.C., cents	2.80 (99.3%)	2.82 (100%)	3.06 (108.5%)

Since block speed is one of the major factors in the D.O.C. equation, the small variation in block speed between  $C_f$  values of .0025 and .0032 corresponds to 0.7 percent change in D.O.C. Raising the coefficient of friction to .0045, however, reduces the block speed significantly and increases the D.O.C. 8.5%.

It can be concluded that low values of coefficient of friction do not appear to appreciably improve the Lift/Cruise Fan D.O.C. However, higher values have a significant impact on the economics of the vehicle. It is therefore important to achieve an aerodynamically clean design.

The sensitivity of the aircraft to engine weight, in terms of gross weight, block speed, and D.O.C. are shown in the following table.

LIFT/CRUISE FAN VTOL  
SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
AND D.O.C. TO ENGINE WEIGHT

500 Statute Mile Range

Engine Weight Factor	Engine Weight .75 Wt. Factor		Engine Weight 1.0 Wt. Factor		Engine Weight 1.25 Wt. Factor	
Gross Weight, lb	67,200	(96.0%)	70,000	(100%)	73,000	(104.3%)
Block Speed, knots	356.2	(100.1%)	355.8	(100%)	355.3	(99%)
D.O.C., cents	2.78	(98.6%)	2.82	(100%)	2.86	(101.4%)

For this evaluation the engine weights were changed to 75 percent and 125 percent of their original values while maintaining a constant thrust. The thrust being unchanged, the variations in block speed are small. Because of the relatively minor importance of the weight factor in the D.O.C. equation the 4 percent variation in gross weight results only in a 1.4 percent change in D.O.C., either way.

The D.O.C. sensitivity to cruise speed is tabulated below.

LIFT/CRUISE FAN VTOL  
SENSITIVITY OF D.O.C. TO CRUISE SPEED  
500 Statute Mile Range

Mach No.	.805	.750	.700	.650	.600	.550
D.O.C., cents	2.82 (100%)	2.90 (102.8%)	3.00 (106.4%)	3.12 (110.6%)	3.26 (115.6%)	3.43 (121.6%)

Reduced engine power settings were used to reduce cruise speed. The D.O.C. varies inversely with cruise speed. The speed of the selected lift/cruise fan vehicle falls in the flat section of the curve indicating an optimum speed range. Higher speed, however, would move the vehicle further up along the drag rise curve adding significantly to the thrust and fuel requirements and resulting in higher D.O.C.

Since the vehicle gross weight and the fuel weight are maintained constant the design mission is not identical throughout the speed range, however, the results are representative of the D.O.C. sensitivity to cruise speed.

The results of the trade-off study between reserve fuel weight and additional passengers, and the resulting sensitivity of D.O.C. to stage length, are shown in the following table. The aircraft total fuel reserve was eliminated and replaced by an equivalent fuselage-passenger weight. A weight increment of 200 pounds was used for each passenger and baggage, plus 105 pounds per passenger corresponding to the additional length of fuselage, seat and equipment. This revision increased the passenger load from 120 to 144 and reduced the D.O.C. by 20.6 percent. Because of the form of the D.O.C. equation this percentage remains constant for all stage lengths.

LIFT/CRUISE FAN VTOL  
144 PASSENGER  
SENSITIVITY OF D.O.C. TO STAGE LENGTH

Stage Length, Statute Miles	25	50	100	200	500	500 (120 pass.)
D.O.C. , cents	9.94	5.79	3.67	2.59	1.97	2.37
	505%	294%	186%	131%	100%	120%

The aircraft sensitivity to specific fuel consumption, in terms of gross weight, block speed, and D.O.C. is shown in the following table.

LIFT/CRUISE FAN VTOL  
 SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
 AND D.O.C. TO SPECIFIC FUEL CONSUMPTION  
 500 Statute Mile Range - T/W Constant

Specific Fuel Consumption	SFC .9 Basic	SFC Basic Configuration	SFC 1.1 Basic
Gross Weight, lb	67,200 (96%)	70,000 (100%)	72,800 (104%)
Block Speed, knots	356 (100.1%)	355.8 (100%)	355 (99.8%)
D.O.C., cents	2.71 (96.1%)	2.82 (100%)	2.94 (104.3%)

A variation of  $\pm 10$  percent in SFC has an appreciable effect on the D.O.C. A major factor, block speed, naturally remains nearly constant. However, the variation in D.O.C. is larger than would be normally expected from the corresponding change in gross weight. This is due to the fuel cost factor included in the D.O.C. equation. From these results it appears that further improvement in engine SFC would result in appreciable savings in vehicle direct operating cost.

The aircraft sensitivity to control power, in terms of the gross weight, block speed, and D.O.C., is shown in the following table:

LIFT/CRUISE FAN VTOL  
 SENSITIVITY OF GROSS WEIGHT, BLOCK SPEED  
 AND D.O.C. TO CONTROL POWER  
 500 Statute Mile Range

Control Power	Control Power .5 Basic	Control Power Basic Configuration	Control Power 2 x Basic
Gross Weight, lb	66,700 (95.3%)	70,000 (100%)	76,600 (109.4%)
Block Speed, knots	353 (99.2%)	355.8 (100%)	356 (100.1%)
D.O.C., cents	2.70 (95.8%)	2.82 (100%)	3.10 (106.2%)

The various levels of control power indicated are achieved by varying the thrust capability of the controls in all three axes. The amount of engine gas bleed-off and the total installed propulsion power requirements are adjusted to satisfy the new control conditions. The vehicle tail areas are maintained constant.

It can be seen from the results that the control power requirements for lift/cruise fan VTOL aircraft have an appreciable effect on vehicle D.O.C. VTOL control criteria must be accurately determined in order to achieve proper design optimization.

### Stopped Rotor VTOL

Vehicle Comparison. - Figure 41 shows a comparison of the characteristics of the minimum D.O.C. aircraft for each of the four stopped rotor concepts considered in the study. The twin rotor vehicles are significantly heavier than the single rotor vehicles. This is primarily due to an increase in propulsion weight and fuel requirements. The propulsion system weight is higher for twin rotors since the minimum D.O.C. aircraft require a higher disc loading to offset the increase in drag associated with trailed blades in cruise flight. Also, a low disc loading forces the wing span to be increased, which increases the wing weight. There is also a wing weight penalty associated with mounting the rotors on the wing tips. The fuel requirements increase due to the increase in vehicle drag of the twin rotor vehicles. The single-rotor, propeller driven aircraft was selected as optimum from these four concepts since it has the minimum D.O.C. The next most competitive concept is the single rotor, turbofan driven aircraft. However, it has a higher D.O.C. even though it is slightly lighter and has a higher cruise speed. This is due entirely to a higher engine cost based directly on price quotes from the engine manufacturers. The turbo fans were sized for hover requirements which results in a cruise Mach number of about 0.76 at 35,000 feet.

Differential propeller thrust for anti-torque was not considered in this study because other in-house work (unpublished) has shown the tail rotor to be the most efficient overall method in this application. The tail rotor is to be stopped in horizontal position pointing into the direction of flight. For this reason, the tail-rotor drag was assumed to be very small and was not considered.

The vehicles discussed above were optimized based on present rotor technology on which the rotor figure of merit drops sharply with increasing tip speed. It is felt that additional development of rotors with more propeller-like characteristics could significantly raise the figure of merit at higher tip speeds as discussed in the Recommended Research and Development section of this report. Figure 42 shows a comparison of the characteristics of the minimum D.O.C. aircraft for present rotor technology and advanced propeller technology rotors. The final selected stopped rotor utilizes propeller technology rotor blades since it is felt that this application is consistent with the state of the art assumed for the other concepts studied. Propeller versus rotor technology is discussed in the Tilt Rotor - Introduction Section on Page 31.

General description. - The general arrangement of the 60 passenger stopped rotor is shown in Figure 43. In VTOL mode the aircraft retains the hover characteristics of a low disc loading helicopter by using a simple three bladed main rotor to provide hover lift. In cruising flight the rotor is progressively unloaded, folded and stowed on top of the aft fuselage compartment and the conventional high loading wing provides cruise lift.

The wing planform has  $0^\circ$  sweepback, 0.6 taper ratio, and aspect ratio of 6. In order to achieve high cruise efficiency the wing loading is 120 pounds per square foot. A NACA 64 series airfoil is used with a wing thickness ratio of 0.14 at the root and 0.12 at the tip. Full span flaps are attached to a conventional wing structure to relieve wing down-load in hover and to improve wing  $C_{L_{max}}$  during transition and emergency wing lift landing.

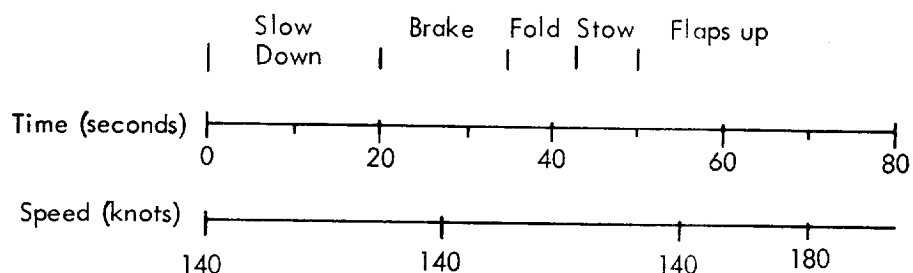
The propulsion system diagram Figure 44 shows the gearing and cross shafting inter-connecting the engines, cruise propellers, main and tail rotors. Four GE 1/S1A free turbine turboshaft engines mounted in pairs in underslung wing nacelles drive two 16-ft diameter conventional propellers through a gear reduction box and clutches. An overrunning clutch on each engine output shaft automatically disengages the engine from the propulsion system in case of failure. Two high speed shafts in each wing leading edge drive the main rotor gear box through individual  $90^\circ$ -angle drives. The antitorque rotor is driven in a conventional manner from the main gear box. Two brakes and clutches located in each engine nacelle disconnect the turboshaft engines from the vertical lift system and stop both rotors during transition. The main rotor is designed for a 13 pounds per square foot disk loading and a maximum tip speed of 900 feet per second. The tail rotor maximum tip speed is 900 feet per second.

The weight statement for the 60 passenger stopped rotor VTOL is shown in Figure 45. There is a 2400-pound penalty associated with stopping and starting the rotor. This corresponds to 3.4 percent of the gross weight.

The transition from hover mode to cruise flight is achieved as follows: The aircraft accelerates from hover to approximately 140 knots as a compound vehicle with flaps down to achieve higher  $C_L$  and unload the rotor. The rotor is de-clutched and the brakes energized to stop both rotors while the vehicle speed is held to approximately 140 knots. The rotor is locked with one blade trailing and the two forward blades are rotated aft to the proper position for stowing. The main rotor supporting linkage is rotated forward to retract the whole rotor and hub assembly on top of the fuselage.

The following diagram shows the time and speed history for the various transition sequences discussed above.

## TRANSITION SEQUENCE - HOVER TO CRUISE



The blade folding mechanism is a simple hinge system using one of the blade attachment pins as pivot point. The main rotor retraction and stowing system operates in a manner similar to a conventional landing gear retraction system. A cylinder releases the uplock mechanism and the hub supporting arm is rotated forward and down hydraulically lowering the hub and the blades into a stowed position. Several fuselage doors cover the hub and blade assembly to provide an aerodynamically clean fuselage configuration.

The rigid rotor principle, with free gyro control throughout as RPM is reduced, permits stopping of the blades in flight during transition. The stopped rotor aircraft is capable of landing in a STOL mode with rotor folded in an emergency operation.

Recent studies have shown that "gas coupling" as opposed to a mechanical drive system between the four gas generators and the main rotor gear box eliminates complex and heavy gear boxes, clutches etc., resulting in a small net weight saving and appreciable simplification of the transmission system proper. This subject is further discussed in section "Recommended Research and Development."

## ECONOMIC ANALYSIS

### Discussion

The purpose of the economic analysis is to provide a numerical basis for comparison of various V/STOL concepts to determine which are the most promising for development into a successful commercial short haul transport.

Ideally, an economic comparison involves consideration of total system revenues and expenses. However, the purpose of this study is also to indicate specific research work that is required to develop useful commercial V/STOL aircraft. The emphasis of the study is, therefore, on aircraft design. Economic aspects have been considered to the extent that these affect the design of each V/STOL concept. Economic comparison has therefore been confined to aircraft direct operating costs (D.O.C.), expressed in cost per available seat mile.

The economic analysis output is summarized in the table on the following page. The D.O.C. of each of the 13 initial 60-passenger vehicles which were evaluated or evolved from the original concept development phase was computed based on a 500-mile stage length, 10.25-minute fixed time, and a total commercial market of 300 vehicles. These D.O.C. values were used as the primary figure of merit in the selection of the most promising vehicle concepts for further design study and cost evaluation, and therefore each vehicle design was optimized for this particular stage length. The D.O.C. of the final selected parametric vehicles, both 60- and 120-passenger configurations, was computed for many various operational conditions (stage length, fixed time, total yearly utilization time) and two potential markets (commercial and military-commercial exclusively). The last column represents the final point design vehicles, six 60-passenger and five 120-passenger, and indicates a D.O.C. computation based on a 500-mile range stage length.

In addition, many various D.O.C. sensitivity studies were conducted on each of the final parametric vehicles and the results are presented and discussed under each vehicle section.

Direct operating costs (D.O.C.) are those costs associated with operating an aircraft exclusive of overhead costs. D.O.C. usually consists of five major categories: crew, fuel and oil, insurance, depreciation, and maintenance.

The factors influencing D.O.C.'s, expressed in terms of available seat miles (ASM) are shown in functional form in the following simplified equation:

$$\frac{\text{D.O.C.}}{\text{ASM}} = f \left[ \frac{\text{Constants} + \text{Weight} + \text{Fuel Consumption} + \text{First Costs (Weight} + \text{Thrust)}}{\text{Block Speed} + \text{Stage Length} + \text{Number of Seats} + \text{Time Between Overhaul} + \text{Utilization} + \text{Depreciation Period}} \right]$$

ECONOMIC ANALYSIS OUTPUT

DESIGNS	INITIAL PARAMETRIC (13 VEHICLES)	FINAL PARAMETRIC (5 VEHICLES)					FINAL DESIGN (6 VEHICLES)	
CONFIGURATIONS (NO. OF PASSENGERS)	60	60	120	60 & 120	60	120	60	120
MARKET	300 Commercial Vehicles	600 Commercial & Military Vehicles	300 Commercial Vehicles	300 Commercial Vehicles	300 Commercial Vehicles	300 Commercial Vehicles	300 Commercial Vehicles	
AIRCRAFT COSTS	Including RDT&E	Excluding RDT&E	Including RDT&E		Including RDT&E	Including RDT&E	Including RDT&E	
FIXED TIME (MINUTES)	10.25	10.25	8.25	6.25	10.25	6.25	VTOL 6.25 STOL 8.25	10.25
YEARLY UTILIZATION TIME (HOURS)	2000	2000	2000	3000	4000	2000	2000	2000
D.O.C.	500 Statute Miles Range	25 50 100 200 500	Statute Miles Range			Hypothetical Mission	500 Statute Miles Range	

Specific physical characteristics of the aircraft influence D.O.C. to the extent that they affect weight, speed, fuel consumption, and power. The two most important aircraft characteristics are weight and speed, assuming a fixed size expressed in the number of seats.

The Short Haul Transport Direct Operating Cost Model is based on the 1960 version of the Air Transport Association Standard Method of Estimating Comparative Direct Operating Costs of Transport Airplanes. All D.O.C. costs are in 1965 dollars.

There are five major cost categories in the D.O.C. model: crew, fuel and oil, insurance, depreciation, and maintenance. Of these five categories, only the maintenance cost formula varies significantly from the ATA method. The formulas for each of the five major categories of direct operating costs and total aircraft as well as the assumptions are included in the Addendum Report.

### Concept Comparisons

Vehicle concepts. - Since the final design and sensitivity studies were conducted concurrently toward the end of the study the following cost sensitivities and comparisons are for the final parametric aircraft, however, they are directly applicable to the final vehicles.

A D.O.C. comparison of the 60-passenger VTOL and STOL concepts is shown in Figure 46 for the 500 statute mile stage length, the mission for which these aircraft were optimized. The costs are based on a commercial production of 300 aircraft including research and development costs (RDT&E); annual utilization and fixed (non-productive) time are 2000 hours and 10.25 minutes, respectively. Fixed time represents the time required to land, takeoff, and taxi. An air maneuver time, or go-around time, of 4.25 minutes is included in the definition of the "fixed time."

The direct operating costs of the 60 and 120-passenger VTOL and STOL aircraft based on a total production of 300 aircraft, including research and development costs (RDT&E) are presented in Figure 47 for five different stage lengths. This figure also includes the direct operating costs of the 60 passenger vehicle based on a total production of 600 aircraft (300 commercial and 300 military) with the research and development costs absorbed by the military program exclusively.

The effect of stage length on D.O.C. does not change the relative ranking of the 120-passenger vehicles; the D.O.C. of the 60-passenger jet flap STOL, however, increases slightly faster with shorter stage length than the D.O.C. of the 60-passenger tilt rotor VTOL and the ranking of these two vehicles is reversed. The percentage D.O.C. increases with shorter stage length is correspondingly higher for the higher cost vehicles.

The effect of the military program on total aircraft costs is to reduce them by one-third. Unit costs have been reduced not only because of the absorption of the RDT&E costs but also due to the lower production cost per unit as the production quantity increases. As shown in Figure 47, the effect of the military program does not alter the relative ranking of the 60-passenger aircraft since it represents a similar D.O.C. improvement (15 to 20 percent) for all vehicles. The percentage D.O.C. improvement is slightly larger at the shorter stage length.

The D.O.C. distributed among the five major cost categories is shown in Figure 48 with a percentage distribution among these cost elements.

A comparison of the total costs of the five 60 and 120 passenger V/STOL concepts is shown in Figure 49. The total aircraft costs are based on the production run of 300 aircraft, including research and development costs (RDT&E). The cost of each major component, including RDT&E, is also shown separately.

The original cost estimating relationships for the Short Haul Transport D.O.C. model were developed for the 60-passenger versions. Costs for the 120 passenger vehicles were derived on a weight basis from the curves for the smaller aircraft. This method leads to relatively large RDT&E costs for the 120-passenger aircraft. Although these values contribute to a slightly higher total aircraft cost they do not affect the cost relationships between the various vehicles.

#### D.O.C. Sensitivities

The sensitivity of direct operating costs to changes in several key variables is discussed below. The sensitivities to changes in the size of the aircraft (expressed in the number of seats), utilization, fixed (unproductive) time, and engine cost were ascertained for each of the vehicle types. The D.O.C.'s were also computed for each of the 60- and

120-passenger aircraft operating over a hypothetical mission, as well as for the final design aircraft at the 500-mile stage length. In addition, D.O.C. sensitivity to changes in key variables which affect only one or two of the V/STOL concepts was also determined and the results are presented in the Design Study Results Section under each particular vehicle heading. They include:

Deflected slipstream STOL 2000 ft

D.O.C. Sensitivity to:	Tail size (area)
	Field length
	Flap/wing chord
	Skin friction coefficient
	Flat rated engine

Jet flap STOL 2000 ft

D.O.C. sensitivity to:	Engine by-pass ratio
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Fan-in-Wing STOL 1000 ft

D.O.C. sensitivity to:	Cruise speed (Mach Number)
	Lift coefficient ( $C_{L_{max}}$ )

Tilt rotor VTOL

D.O.C. sensitivity to:	Rotor weight
	Transmission weight
	Drag coefficient
	Flat rated engine

Lift/Cruise fan VTOL

D.O.C. sensitivity to:	Engine weight
	Number of generators
	Skin friction coefficient
	Control power
	Cruise speed (Mach Number)
	Specific fuel consumption

Although these D.O.C. sensitivity studies were conducted on an individual aircraft, several can be considered representative of other similar types of vehicles (e.g. skin friction coefficient, cruise speed)

Aircraft size (number of seats). - Doubling the payload (expressed in the number of seats) is one of the most effective ways of lowering operating costs as shown in Figure 50. It can be noted that the relative ranking of the 60-passenger jet flap STOL and tilt rotor VTOL, respectively 2 and 3, based on D.O.C. values is reversed for the same 120-passenger vehicles, indicating a slightly larger D.O.C. improvement with heavier payload for the tilt rotor vehicle.

Aircraft utilization, expressed as the number of hours the aircraft is in service each year, is equally as important as the number of seats in affecting operation costs. Its effect is almost wholly on insurance and depreciation costs. Doubling the annual hours of utilization from 2000 (5.5 hours a day) to 4000, reduces operating costs by 22% to 30%. Figure 51 represents a typical example of variation in D.O.C. at various stage lengths for 2000, 3000, and 4000 hours of yearly utilization.

Fixed time. - Fixed time, or unproductive time, represents the time required to land, takeoff, and taxi, plus an air maneuver time or go-around time of 4.25 minutes.

A fixed time of 10.25 minutes was considered as the standard for the D.O.C. computations: 4 minutes for taxi and ground delays at origin and destination, one minute for takeoff and one minute for landing, and 4.25 minutes air maneuver time. To test the sensitivity of operational improvements, D.O.C.'s were also computed using a fixed time of 4 minutes: 2 minutes for taxi and ground delays, and one minute for landing and one minute for take off. A fixed time of 2 minutes was also used to compute D.O.C.'s for the two VTOL aircraft: one minute for landing, one minute for take off and no taxi time. The 2-minute fixed time was utilized in operations, under the "Corridor Concept." (See Operational Analysis.)

D.O.C.'s are not very sensitive to changes in fixed time at longer stage lengths. At shorter stage lengths, however, the effect is more significant, as shown in Figure 52. The two bands represent the range of percentage improvement in D.O.C. for 6.25 and 8.25 minute fixed time compared to 10.25 minutes fixed time for all five selected vehicles. The rotor type vehicles showed the least improvement and the fan types are represented by the higher curves.

Engine Costs. - D.O.C. estimates were made for each of the concepts assuming that engine costs would be one-half and double the original cost estimate. As expected, only in the concepts requiring high power (Lift/Cruise Fan, Fan-in-Wing, and Jet Flap) is there any significant impact of the change in engine costs as shown in Figure 53.

Hypothetical mission. - Another check of the D.O.C. sensitivity to operations was made by calculating the costs of operating each VTOL and STOL over the 720 mile mission shown in Figure 54. The starting and returning points are at A. All vehicles refuel at airports A, C, and E and take off at a gross weight which includes only the fuel required for the mission plus 1/2 hour loiter. The VTOL aircraft use VTOL landing and take off mode at all airports. A comparison between the direct operating costs based on the 500 statute miles stage length and the hypothetical mission direct operating costs shows that the percentage increase in D.O.C. is relatively small for the tilt rotor and deflected slipstream (on the order of 15% for the 60-passenger vehicle), but goes up rapidly for the other vehicles in the relative order, lift/cruise fan, jet flap and fan-in-wing. The fan-powered aircraft experience higher D.O.C.'s because the increased use of lift fans in take-offs and landings increase the maintenance costs. A similar progression is applicable to the 120-passenger vehicle although the percentage increase is slightly larger for the larger aircraft.

It can also be noted that the relative ranking of the 120-passenger vehicles remains unchanged. The ranking of the 60-passenger aircraft is modified such that the tilt rotor VTOL becomes cheaper than the jet flap STOL 2000-ft and the lift/cruise fan precedes the fan-in-wing.

This evaluation indicates the importance of using ground rules based on realistic airline operational procedures in order to conduct a valid economic evaluation of various aircraft designs.

A breakdown of segment fuel in pounds for this mission is shown in Figure 54.

## OPERATIONAL ANALYSIS

The operational analysis includes an evaluation of the feasibility of short haul VTOL and STOL type aircraft operations in congested areas, as well as an evaluation and comparison of each study vehicle based on airworthiness, safety, maintainability and noise factors. The results of this study together with the cost data previously presented provide the means necessary to assess the feasibility of the various vehicles and a basis for selection of the most promising vehicles for short haul transportation.

Projected short haul transport operation in the New York metropolitan area is presented first, with a discussion of the "corridor concept". Los Angeles, although typical of large metropolitan areas, presents a different operational environment and is evaluated on a comparative basis.

#### Metropolitan Area Service

Major requirements for commercial service by V/STOL aircraft include the ability to operate in non-fixed wing airspace, in all-weather conditions and within acceptable levels of noise. The New York and Los Angeles metropolitan areas are selected for examination as representing extremes of economic and operational environments. The New York area is the most congested area both in the air and on the ground and is a most likely area for the development of V/STOL service. Los Angeles is the most decentralized of the larger metropolitan areas. Competition from the automobile and fixed-wing aircraft are expected to retard comparable development of inter-city V/STOL service in the Los Angeles area within the next decade.

New York Area. - The New York airspace already experiences traffic congestion during some hours of the day. These periods of peak congestion will grow longer if no major changes are made within the next decade. Two approaches which have been suggested to relieve the congested airspace in the New York area are: an additional airport, or better utilization of existing airports.

An additional airport could relieve congestion in the air. However, since any new major airport would be farther from midtown Manhattan than existing airports, total trip time and cost will increase because of the longer ground distances. Increasing capacity at existing airports will ease airspace congestion to some degree. But ground congestion at the airports, and from the airports to midtown Manhattan, will result in increased total trip time and cost. The time lost because of air and ground congestion is a small percentage of total trip time for long distance trips. On trips of less than 300 miles, however, congestion may increase total trip time and cost by one-third. The two proposed solutions to the airspace congestion problem are thus not really solutions as far as the short haul passenger is concerned.

The problem of inter-city short haul transportation may be solved, however, by V/STOL aircraft service into mid-Manhattan. In essence, this brings the additional major airport right into the core area. To have a significant impact on the problem of airport congestion, the midtown terminal must be able to handle a passenger volume, equivalent to La Guardia Airport, of approximately 4.5 to 5.0 million annually. This requires a peak hour capacity of about 40 movements (landing and takeoffs).

Midtown V/STOL terminal: Regardless of the type of aircraft, VTOL or STOL, it is estimated that a minimum area of 35 acres is required to process upwards of 5 million passengers annually. This includes the terminal building, gate position, the apron, automobile parking, taxi and bus areas and entrance roadways. The area required for landings, takeoffs and taxiings, is a function of the runway length required for each type of aircraft. This will range from as little as 12 acres for VTOL aircraft, to 27 acres for STOL 1000 ft. aircraft.

The total area required for a V/STOL terminal need not be on one level, and in view of the scarcity of land in the core area and its high costs a multi-level terminal is economically justified. For example, an artist's concept of such a 4-story VTOL terminal is shown in Figure 55 with overall dimensions of about 1000 ft x 500 ft; it can handle the 5 million annual passengers with a maximum of 8 gate positions. Two stories are used for auto parking, one for taxi and bus area, another for passenger handling and servicing, and the roof is the flight deck. Ironically, the overall size of the terminal is a function of auto parking rather than aircraft operation.

A potential site for such a terminal in mid-town Manhattan is along the Hudson River at West 30th Street. This location is attractive because the river may be used as an approach corridor; its proximity to railroad yards will alleviate problems due to aircraft noise; it has good highway access; and it is close to the subway system. Land acquisition costs should be relatively low.

Operations from such a terminal are feasible, as demonstrated by New York Airways current helicopter operation. The helicopters operate below an altitude of 1500 feet, in non-fixed wing airspace. Using a Decca Navigation System these vehicles have a navigational accuracy of  $\pm 70$  feet.

Minimum vehicle spacing should be an order of magnitude greater than the position accuracy. The resulting spacing, 700 feet, together with the maximum number of movements per hour (40) indicates that this spacing can be held essentially to touch down. This large spacing indicates that current navigational systems can allow the necessary airspace utilization with safety. It should be noted that this conclusion is only valid for an area-type navigation system, such as Decca, in which the pilot is continuously provided with a clear display of his position relative to the ground. Before such systems will be acceptable to pilots in high traffic density operations, the displays must include positions of all other aircraft within the pilot's area of interest.

Corridor concept: Even with a midtown terminal there would be no net increase in the region's airport capacity if the aircraft entered the airspace used by fixed wing aircraft. Airspace congestion will be relieved only if the aircraft operate in their own airspace as they enter the core area. The northwest New Jersey area could be used for a staging area for flight operations to and from mid-Manhattan. A corridor, or controlled route, under fixed wing aircraft altitudes and away from other airport approach patterns would connect the staging area with mid-town Manhattan. With such an approach, the terminal would increase the combined capacity of the regional airport system.

As shown in Figure 56, V/STOL aircraft from Boston, Washington, and other cities would enter the staging area at cruise altitude and speed. These aircraft would then be routed into one of the several "corridors" into mid-Manhattan by an air traffic controller located in the staging area.

Los Angeles Area.— The previous discussion indicates that V/STOL operations are probably feasible in the densely-populated, congested New York area. In the Los Angeles area, congestion is not as severe on the ground as in the New York area, and neither Los Angeles International Airport nor the surrounding airspace is as congested. There is little doubt that V/STOL aircraft can be operated in this area without reducing fixed-wing capacity.

At present, Los Angeles Airways offers helicopter service from Los Angeles International Airport to a number of cities within a radius of about 50 miles. These include Burbank, Van Nuys, Glendale, Ontario, Riverside, Disneyland, and Newport Beach.

With regard to fixed wing air traffic, Los Angeles international Airport can be expanded to handle the expected growth in traffic during the next 20 years. Expanded short-haul air service from the satellite airports can be expected to ease some of the congestion at Los Angeles International Airport. The bottleneck to the smooth flow of future air traffic in the greater Los Angeles area will probably be ground accessibility to Los Angeles International Airport, especially during peak commuting hours.

A proposed solution to the problem of airport ground accessibility is to provide helicopter service to the airport from a downtown location (possibly the air space above Union Station) as well as from other locations in the greater Los Angeles area. Service would be furnished by helicopters in the first phase of a downtown to airport air service. Future vehicles should have V/STOL capability to keep land acquisition costs to a minimum. In the second stage of development, the V/STOL terminals would be used in intra-metropolitan area service (distances to up 100 miles) as well as inter-city service to such cities as San Diego, Las Vegas, Fresno, and San Francisco.

V/STOL aircraft movements from most of the aforementioned terminals would be approaching from the north or south, and would not be operating in fixed wing aircraft air space. Their ability to navigate with the required precision under these conditions has been discussed in the analysis of New York's airspace.

Conclusion. - It is believed that V/STOL aircraft can operate in a congested area such as New York or Los Angeles under the proper conditions, and that a sizeable number of operations can be made from a midtown terminal. Using the "corridor" concept, airspace used for approaches to existing airports will not be further congested. V/STOL aircraft may be the solution not only to the short haul inter-city passenger problem, but may also ameliorate the problems of airport and airspace congestion.

#### Federal Aviation Regulations Evaluation

A brief examination of the Federal Aviation Regulations Part 25, Part 29 and Part 121 was made to determine what major changes would be required in order to certificate and operate V/STOL aircraft. Part 25, "Airworthiness Standards: Transport Category Airplanes," does not contemplate the radical departures from conventional performance that are feasible

with V/STOL aircraft. Any such changes will logically be the subject of continuing discussions between the airlines, the airframe manufacturers, and the FAA. Each paragraph will have to be examined carefully to be certain that realistic requirements are established without creating conditions that will render the use of these aircraft impossible from the economic standpoint.

Two of the most significant differences between V/STOL type aircraft and conventional aircraft presently covered by the regulations occur during the transition and hovering flight conditions. This extension of the flight envelope reflects strongly upon the stability and control requirements, on the power level requirements, and the safety and reliability aspects of the propulsion system design.

Recommendations for revisions to the Federal Aviation Regulations relative to stability and control will have to be based on extensive flight simulator investigation and direct flight test data for each particular flight condition.

Because V/STOL aircraft are normally characterized by relatively high thrust to weight ratios necessary to insure suitable safety margins during landing and takeoff with engine failed, the various climb requirements listed in the regulations will probably not be controlling factors for the propulsion system design of V/STOL type vehicles.

The stalling speed as defined in FAR Part 25 would not apply to a VTOL aircraft and would not be satisfactory for a STOL airplane where the level of thrust has a great bearing on the stalling speed. Similarly, other FAR 25 low speed regulations such as takeoff and landing speeds, trim speeds, minimum control speeds, climb speeds, structural speeds, and the speed indicator reading range are not directly applicable to V/STOL aircraft. The landing gear loads specified in FAR Part 25 include the effects of aerodynamic wing lift up to the weight of the vehicle. An equivalent up load due to the lift engines would be applicable to VTOL type vehicles in the STOL mode of operation, with some combination of lift engine thrust and aerodynamic lift at forward speeds up to the speed for takeoff with lift engines inoperative.

An amendment to FAR Part 121 proposes to extend the accelerate-stop distance by 800 feet for turbojet aircraft. This requirement appears too stringent for vehicles capable of very short ground roll and low speed takeoff. It is suggested that a ground roll time limitation would be more suitable.

Regulations controlling maximum pilot effort should be coordinated to establish common values for both Part 25 and Part 29.

### Safety and Maintainability

The acceptance of a particular vehicle for operation in a short haul transport system is closely related to its overall operational safety and one of the primary design constraints was to provide each VTOL and STOL vehicle with the capability to maintain flight or to land under IFR conditions after sudden loss of one engine at any time. In addition to this engine fail safe requirement the safety study includes an analysis of each vehicle system and subsystem in terms of safety and crashworthiness to guide the design of the individual aircraft and provide means for comparison between the various vehicles.

An analysis of maintainability is based mainly on an evaluation of the accessibility to the main components and systems requiring fairly frequent maintenance, and of their complexity. Where feasible, the vehicle designs were revised to reflect improved maintainability.

Safety. - All VTOL vehicles have sufficient power to hover with one engine inoperative. The STOL aircraft are designed to meet FAA critical field length criteria. Level flight can be maintained by all configurations with two engines inoperative, although a safe landing under these conditions would require additional runway length. The safety aspects of structural or engine failure have not been further considered in this analysis.

The tilt rotor, the fan-in-wing, the lift/cruise fan aircraft, and stopped rotor vehicle each have more than one engine installed in a single nacelle. Safety is less than maximum since a structural failure of one engine could damage the adjacent engine. Armor plating between engines or some other means to contain a bursting wheel could alleviate this problem at the cost of some additional weight.

A failure in any of the engine exhaust gas manifolding or reaction control ducting in the lift/cruise fan, fan-in-wing, and the jet-flap aircraft could have catastrophic effects. Failure of the high pressure bleed system used for rudder boundary layer control of the deflected slipstream aircraft would result in impaired directional control, but the low gas temperature (550° - 600°F) makes this concept less vulnerable.

The tilt rotor and deflected slipstream aircraft require overrunning clutches, reduction gearing, and high speed shafting to interconnect the engines. Failure in these systems could result in catastrophic results or in passenger compartment damage.

The V/STOL aircraft are particularly exposed to foreign object damage to the engine compressors. The tilt rotor airplane is less vulnerable than other types since air impingement velocity at the ground is comparatively low, and the engine air inlets are well above the ground. The proximity of the inlets to the ground, the downwash velocities, and the engine inlet positions of the other types, however, make them more susceptible to foreign object damage.

The crashworthiness evaluation covers the more critical characteristics of each vehicle; many are common to several configurations. The high wing configurations of all the V/STOL configurations, chosen mainly because of physical restriction and/or general arrangement limitations, tends to reduce the crashworthiness in comparison with low wing types. Probability of ditching survival is less with high wing configuration than it is for low wing aircraft because of the structural resistance and buoyancy of low wing configurations. Because of the requirement to rotate the nacelles and rotors to a vertical position for landing, the tilt rotor concept suffers from a crashworthiness standpoint. To effect a landing with the rotors in the cruise position would subject the passengers to flying debris when the rotors struck the ground. Except for the possibility of flying propeller parts in the event of a crash the deflected slipstream STOL probably has fewer crashworthiness shortcomings than the other types.

Based on the results of the above safety study, a fail safety rating from 0 to 10 was established to provide a quantitative basis of comparison between the final vehicles.

The rating values of the six vehicles are presented in Figures 60 and 61 and are discussed under the section entitled Vehicle Comparisons.

Maintainability - The factors considered in making a maintainability assessment are:

- Number of items requiring unique maintenance skills or training
- Complexity of control system
- Complexity of lift and drive system
- Anticipated high maintenance and/or inspection requirement items

Deflected slipstream 2000-foot STOL design: The existing knowledge, skills, and techniques practiced by maintenance personnel on current production aircraft can be applied directly with little change to this airplane. The addition of cross-shafting, right angle gearboxes, overrunning and disengaging clutches to the proven turboprop concepts increases the number of maintenance and inspection items. However, the requirement to design these components for maximum safety and reliability should result in reasonable time between inspections and overhaul.

Tilt rotor VTOL design: Rotor systems with their associated cyclic and collective controls are successfully used on present day helicopters but maintenance manhours per flight hour are high. The rotor drive system, transmission shafting, and nacelle tilt systems provide a high number of periodic maintenance items. The proximity of the engines, gearboxes, shafts controls, etc., and associated fire shielding within a nacelle minimizes the accessibility for maintenance, inspection, and component replacement.

Stopped rotor VTOL design: The location of the main rotor gearbox and folding and retracting mechanism above the passenger compartment restrict the access to an area requiring frequent periodic inspection and maintenance. The accessibility is further limited by the installation of several complex mechanical systems within a limited space. The engine nacelle incorporates gearboxes and clutches in addition to two engines, however, the location below the wing contribute to the ease of removal of these components. Main and tail rotor systems with their related controls are similar to present day helicopters and require frequent periodic inspection and high ratio of maintenance manhours per flight hour. The total flight time accumulated on the VTOL propulsion system is small however, since the stopped rotor operates in VTOL mode only for relatively short periods of time during each flight.

Jet-flap 2000-foot STOL design: A high maintenance and replacement potential is anticipated because of exposure of the flaps to extreme temperature gradients existing between takeoff and landing conditions and cruise operation. The large ducts in the wing and fuselage require frequent inspection. The diverter valves are located directly in the hot exhaust gas of the engines, with associated heat, pressure, and high frequency vibration. Maintenance requirements are especially critical for these items. These high level of maintenance requirements for the hot gas system emphasize the need for further study relating to the application of a cold air system to this type of vehicle.

Fan-in-wing 1000-foot STOL design: Engine proximity within the nacelles limits accessibility for maintenance and inspection. Diverter valves and reaction jet nozzles in the fuselage and wing tips and large interconnecting ducts for the lift fans in the wings all require close inspection. The lift fans and associated doors, louvers, diverter valves, actuators, and controls further increase maintenance requirements.

Lift/cruise fan VTOL design: The location of three engines, lift fan, cruise fan, diverter valves, and vectoring nozzles contained in each wing tip nacelle affords poor accessibility for maintenance and inspection. The diverter valves and wing ducting presents the same maintenance and inspection problems present in the jet-flap and fan-in-wing aircraft.

A service maintenance rating from 0 to 10 based on the results on the maintainability study was developed to provide a quantitative comparison between the six final vehicles. The rating values are presented in Figures 60 and 61 and are fully discussed under the section entitled Vehicle Comparisons.

### Noise Analysis

Noise levels in the far field have been studied in considerable detail for two sizes of each of the five basic airplane configurations. The broad variations in configuration and thrust generation result in corresponding variation in far-field noise levels. The relative merits of the various configurations and their noise characteristics are discussed subsequently.

In most cases noise levels were obtained by calculating the intensity level of each source, such as exhaust, inlet, and propeller, and summing them to obtain the combined noise from all sources. Digital computer facilities were used extensively. Contours of peak perceived noise in decibels (PNdB) were developed for each airplane configuration for take-off and climbout, these are presented in the Addendum Report. All contour plots are for full power operation at sea level, standard day conditions and zero headwind. No special noise abatement maneuver or power cutback has been assumed. Likewise the calculations assume a flat, unobstructed terrain with little or no ground cover. The effect of buildings, trees, evaluation and wind can only be considered on an individual airport basis. A summary of these contour plots is presented in Figure 57 in the form of curves for each individual vehicle; these curves show maximum noise level perceived as a function of distance from takeoff point, at the azimuth bearing where the noise travels the farthest distance.

A noise sensitivity study was conducted for five of the 60-passenger vehicles to determine the effects on noise of changes in either tip speed or thrust-to-weight ratio. The results of this study are presented in Appendix C. The results shown in Figure C-9 (static conditions) indicate substantial differences from earlier results. These differences are believed to be a direct result of the use of different computational methods and available data at the time the original study was conducted. Details of the calculation methods used for Appendix C appear in the Addendum Report (LR 20573).

The noise of the aircraft studied is expressed in terms of perceived noise level (PNL) which is one measure of the "noisiness" or annoyance of a sound, it is commonly used in aircraft work. The PNL, expressed in units of PNdB (perceived noise decibels), is derived from subjective tests and relates the noisiness of a broad band noise to an equivalent noisiness of a band of noise centered at 1000 Hz. The PNL is a computed quantity based on octave-band sound pressure level.

Tilt rotor. - The rotors which are the controlling noise source, are in a plane parallel to the ground and thus the noise directivity index is the same in all directions. The noise contours for this configuration hence are circles. The fundamental blade-passage frequency is below the first band of the audible noise spectrum and the higher fundamentals affect only the first two bands. The noise in the other bands arises primarily from the boundary layer on the large rotor blades. The low fundamental blade-passage frequency could cause noticeable vibrations in nearby buildings even when little or no noise is heard. However, since the fundamental frequency is below the audible spectrum, the perceived noise levels will be lower than might otherwise be expected. The peak values shown in Figure 57 are for maximum power at the instant of lift-off.

Lift-cruise-fan. - The contours developed for each aircraft of this type demonstrate the effects of directivity produced when mounting one fan parallel and the other perpendicular to the ground surface. All energy in the gas generator exhaust is assumed to be consumed in driving the lift and cruise fans. The inlet noise is low and highly directional because of the long inlet ducting. The primary noise sources are the lift/cruise fan and the lift fan. Low noise levels are a result of a high mass flow through the fans at low velocity to attain the required thrust. The peak values shown in Figure 57 are for maximum power at the instant of lift-off.

The perceived noise level at a distance of 1000 feet directly to the side of the fans was compared for three different GE type lift fans of equal thrust but different disk loading. The results, as shown by Figure 58 show the reduction of PNdB as disk loading is decreased.

Fan-in-wing. - In this configuration the fans are mounted in the wing parallel to the ground, and the PNdB contours with the aircraft at rest are circles. As the aircraft advances down the runway perceived noise at a given distance from the runway decreases due to increasing airspeed and distance. The fans are the principal noise sources, with some additional high frequency noise produced in the inlet to the gas generators. It is assumed that nearly all of the energy in the exhaust of the gas generators is dissipated in driving the fans; the remaining exhaust energy produces jet noise of a low level. Also, the vortex noise produced by the fans is of a low level. Since the high-frequency fan-blade-passage noise is rapidly attenuated by the atmosphere, the perceived noise level falls off rapidly with increasing distance. As a result, this vehicle is the least annoying at great distances.

Deflected slipstream. - The effect of directivity on far-field noise is significant. The calculated contours indicate that maximum noise is heard at an angle of approximately 120 degrees from the airplane heading. The propeller noise predominates in the first, second and third octave bands and since the levels in these bands are attenuated very little in the atmosphere, they are the primary source of the high perceived noise levels at great distances from the aircraft. The inlet and exhaust noise is predominant in the fourth and higher octave bands, but is much less intense than propeller noise.

Jet-flap. - The perceived noise contours for the 60 and 120 passenger Jet-Flap airplanes indicate that the maximum noise occurs at an angle of 140 degrees from the heading of the aircraft. The primary noise sources are the eight fan exhaust nozzles, eight jet exhaust nozzles, and four engine inlets. The inlet noise predominates in the last two octave bands.

Stopped rotor. - The stopped rotor and the tilt rotor are characterized by similar maximum PNL's. The noise contours for the stopped rotor, unlike the tilt rotor, are not circular because of the asymmetrical location of the tail rotor along the aircraft longitudinal axis. The peak noise level occurs on the left hand side of the vehicle at approximately 30 and 120 degrees from the heading of the aircraft.

The noise analysis was conducted to provide a basis of comparison between the various vehicles and was not used as a criterion for the design optimization of the parametric and final vehicles.

Internal noise. - The 120 passenger jet flap airplane was chosen to examine the soundproofing requirements to maintain a given noise level. The fuselage of the airplane is divided into five sections as follows:

1. Flight station - from most forward point on airplane to 200 inches aft.
2. Forward passenger compartment - from 200 inches aft to 400 inches.
3. Mid-Forward passenger compartment - from 400 inches aft to 600 inches.
4. Mid-Aft passenger compartment - from 600 inches aft to 1000 inches.
5. Aft passenger compartment - from 800 inches aft to 1000 inches.

The noise levels from each noise source were weighted according to blocking of wing, nacelle, and fuselage; distance; and directivity and the three were then combined to obtain the level and spectrum shape of the noise impinging against the skin surface of each of the fuselage sections. A computer program was utilized to determine the internal noise levels in the three speech interference bands (600 - 1200 cps; 1200 - 2400 cps; and 2400 - 4800 cps) at the centerline of each compartment by determining the reduction in noise due to the transmission loss through the skin, soundproofing, and trim panels; and the absorption of seats, carpet, overhead racks, trim panels, etc. Several different weights of soundproofing were added to each section to reduce the levels throughout the airplane. Essential lining, trim, seating, partitioning, and carpeting are included in the baseline configuration and are not part of the soundproofing weight. In most instances the added soundproofing consisted of fiberglass batts placed between the skin and the trim liners. Curves of speech interference level versus weight of soundproofing were established for each fuselage section. These curves are shown in Figure 59. The total aircraft soundproofing weights were then plotted versus speech interference level and are shown in the same figure. All data are for takeoff power at the instant of brake release.

For this study the fuselage skin thickness was assumed to be 0.050 inch over the entire aircraft. Also, when soundproofing of a certain density and thickness was added to a section, it was added to the entire section excepting the floor. A more meaningful curve of the variation of SIL with soundproofing weight could be established if the skin thickness were varied and soundproofing thickness and density were chosen in accordance with skin variation. It has also been assumed that noise in air conditioning ducts is adequately suppressed by the thermal insulation.

A range of desired speech interference level is also shown in Figure 59. The desired range upper level corresponds to 70 db and a total weight penalty of only 280 lb for the 120 passenger jet flap aircraft. This additional weight represents a very small weight fraction especially when it is considered that this particular aircraft is the noisiest of all the vehicles analysed. However the weight penalty increases very rapidly for slightly lower internal noise level, mainly because of the additional soundproofing required in the mid-aft passenger compartment.

## VEHICLE COMPARISONS

One of the objectives of the study was to determine the suitability of each of the vehicles for use as commercial short haul transports. The economic analysis provided one basis for determining suitability, however, there were numerous other qualitative considerations to be evaluated before the most suitable vehicles could be selected. These qualitative factors may, when cost differences are small, result in the best vehicle not being the least costly.

The vehicles have been compared on the basis of the following factors, each of which (except for the last item) has been presented and discussed in detail in previous sections.

- Block speed ( 500 mi. range)
- Direct Operating Cost
- Fail-Safety
- Service and Maintenance
- Takeoff Noise
- Development Risk

These factors have been evaluated by appropriate people in the contractor's organization and the resulting comparisons are shown in Figures 60 and 61 for the STOL and VTOL vehicles. A relative rating scale of 10 is used for the qualitative factors, where 10 indicates the best of the vehicles being compared. In the following section each of the rating factors and the ratings of each vehicle are discussed.

Block speed is an important factor in passenger preference and therefore is important in relation to the load factor assumed in calculating D.O.C. At very short stage lengths cruise speed has little influence on block speed, but even small differences in speed provide differences in passenger preference, and thus in load factor. Therefore block speed must have a large qualitative influence on vehicle selection in addition to its direct effect on direct operating costs.

Fail safety includes a variety of considerations including crashworthiness and secondary effects of system or component failure. As an example, high wing aircraft are considered somewhat less crashworthy than low wing aircraft. Engine nacelles containing more than one engine are considered to accept the risk of mutual damage due to turbine failure and thus have less fail safety.

Service and maintenance is almost directly related to accessibility and estimated frequency of component replacement. Takeoff noise is evaluated close to the airport because of the intended operating in downtown areas.

Development risk is considered judgement of the magnitude of the technical problems that must be solved before the particular type of vehicle would be suitable for commercial use. Such considerations include both the problems and the potential solutions.

### STOL Aircraft

The data shown in Figure 60 for the three STOL aircraft indicate that the jet flap and fan-in-wing vehicles have substantially higher block speeds than the deflected slipstream type, they would therefore provide a passenger preference. However, the sensitivity study on flat rating the engines for the deflected slipstream on page 19 shows that the block speed may be increased 40 mph without resulting in any increase in D.O.C. The fan-in-wing is slightly faster than the jet flap aircraft but at the expense of a higher direct operating cost. However, this is a 1000-ft STOL fan-in-wing and a 2000-ft STOL jet flap.

Figure C-9 shows that for 1000-ft STOL aircraft the fan-in-wing concept has a lower D.O.C. and a lower perceived noise level than the jet flap. For 2000-ft STOL aircraft the jet flap concept has a lower D.O.C., but a higher perceived noise level than the fan-in-wing concept. Also, a sensitivity study on the 1000-ft STOL fan-in-wing on page 30 shows that reducing the cruise speed by  $M .085$ , or block speed 32 mph, results in a decrease in D.O.C. of 7 percent. Fail safety is high for the jet flap and deflected slipstream vehicles because the engines are each mounted in individual nacelles while the fan-in-wing has two engines side-by-side in each nacelle. The wing on the fan-in-wing airplane was not sufficiently large to hold the fuel required, with the result that fuel is carried in the wing center section and in the fuselage which further degrades safety. The service and maintenance ratings reflect the more difficult access to each of the two engines in the nacelles of fan-in-wing vehicle. Jet flap duct system maintenance could be a serious problem but in the present study it was assumed to be directly solvable by careful design and by extensive development testing.

Airport/community noise is a major factor in the selection of STOL vehicles. The jet flap aircraft is the noisiest of this type of aircraft studied. The potential for noise reduction is low for the particular design studied since the major noise source is the high density, high velocity exhaust from the multiple nozzles. Substitution of high by-pass ratio turbofan engines to provide increased mass flow and reduced flow velocities should provide sizable noise reductions. The high noise level associated with the jet flap necessitates a low rating for this vehicle. Of the remaining two configurations the fan-in-wing shows a somewhat higher noise level than the deflected slipstream and as a result has a lower rating than the deflected slipstream.

The relative development risk of the three STOL vehicles is indicated in Figure 60. The deflected-slipstream type has the highest rating, the risk being nearly zero because of the well developed state-of-the-art. Much better flap systems are felt to be possible but these could be developed with little or no risk in meeting performance guarantees. The jet flap airplane is conventional in most respects except for the flap system. The fact that significant improvements in jet-flap duct components are required for adequate service life is the primary area of development risk. The primary development risk in the fan-in-wing is felt to be the control of complex interconnected duct systems from start-up to shut-down and for all emergency conditions.

The above considerations have led to the conclusion that the first preference for STOL vehicles would be the deflected slipstream aircraft since for stage lengths shorter than 500 miles the cruise speed becomes less important as a parameter in determining vehicle preference. The second choice aircraft is very close between the jet flap and fan-in-wing concepts and is dependent on the specific field length requirements. For 1000-ft STOL aircraft the fan-in-wing is more desirable, but for 2000-ft STOL aircraft the jet flap is more desirable.

### VTOL Aircraft

The high block speed of the lift/cruise fan aircraft is definitely advantageous but is accompanied by a high D.O.C. The tilt-rotor vehicle has both a lower D.O.C. and lower cruise speed. The stopped rotor has a higher cruise speed and slightly lower D.O.C. than the tilt rotor. Since the rotor operation time is only a fraction of the flight time there must be a low maintenance cost on this component for the stopped rotor vehicle.

Fail safety is lowest for the lift/cruise fan concept because of the multiple gas generators (3) in each nacelle and because fuel is carried in the wing panels and center section and even then some must be carried in the fuselage to make the 500-mile design mission. The tilt-rotor vehicle has all fuel in the wing but has twin engines in each nacelle. Further this vehicle cannot make a safe emergency landing with the rotors in the cruise position. The stopped rotor vehicle has the best fail safety because of the capability to make landings in both the helicopter and airplane flight configurations. The only major adverse factor is the rotor and gear box located over the passenger compartment as it influences crashworthiness.

Service and maintenance are best with the tilt-rotor vehicle because all three VTOL types have multiple engines per nacelle and they are most accessible for the tilt-rotor vehicle. Rotor and gear box access is also good for this vehicle. The use of three gas generators and an extremely compact multi-valve duct system in the lift/cruise fan limits accessibility and thus this vehicle has the lowest maintenance rating.

The computed noise levels relatively close to the aircraft, Figure 57, indicate that the range of noise falls in the region of 100 to 110 PNdb's for all aircraft except the jet flap. Figure C-9 shows this to be true of the VTOL aircraft also. The high frequency nature of the lift/cruise fan noise results in a rapid noise reduction with increasing distance similar to the fan-in-wing STOL. These results are reflected in the vehicle noise ratings.

The development risk is similar in all three vehicles as is indicated by the close ratings. The lift/cruise fan has the same propulsion and flight control problems as the fan-in-wing aircraft because of the complex duct and valve system. The tilt-rotor has the fail safety problem in emergency horizontal landing. These factors together with the multiple flight mode capability of the stopped rotor vehicle indicate that it has the least development risk.

The order of preference indicated in Figure 61 shows the stopped rotor as first choice for VTOL aircraft, the tilt rotor as second choice, and the lift/cruise fan as third choice.

## RECOMMENDED RESEARCH AND DEVELOPMENT

The numerous side studies, the parametric economic study, and sensitivity analysis that were conducted as parts of the total program have all suggested research and development projects. Many of these projects are related to specific types of vehicles and a few are more general and apply to groups of vehicles or to all the vehicles that were investigated. In the following no attempt is made to differentiate between research and development.

Noise. - Noise should be one of the primary design variables for aircraft intended for service in metropolitan and suburban areas. None of the aircraft investigated has completely acceptable noise characteristics. Methods of noise reduction are fairly well established; however, many of the restrictions, or ground rules, used for the noise sensitivity study (Appendix C) prevented realization of the full potential for noise reduction for some of the vehicle configurations. Some of these restrictions and ground rules are: (1) Vehicle performance envelope (result of vehicle design) (2) Practical vehicle size which limited propeller and rotor sizes (3) Reasonable D.O.C. limits (4) Use of fixed propeller sizes as tip speed was varied. In addition to changes in tip speed, such changes as reduced disc loading and increased number of blades should also be considered. The use of high by-pass ratio turbofan engines to increase mass flow and reduce flow velocities

would probably reduce the noise of the jet - flap aircraft. Noise from the fan-in-wing can be reduced by use of reduced tip speeds and reduced disc loadings. In general, for any given vehicle configuration, the design requiring the lowest power has the lowest noise level, when all other noise reduction procedures are followed. However, the design with the lowest noise levels may not be physically or economically feasible. A tradeoff study is essential for optimizing short haul vehicles for minimum noise within reasonable economic restrictions. In addition, noise prediction methods for existing and new propulsion devices should be improved and correlated with experimental results. Before current and future V/STOL aircraft can be evaluated properly, acceptable noise levels for various community V/STOL airport locations should be established. These requirements will not only determine the size and type of vehicle which may operate in any specific location, but will provide a design criterion for future vehicles.

VTOL control criteria and handling qualities. - One of the more pressing areas for research is embodied in the need for a realistic definition of V/STOL control criteria and handling qualities. At the present time there are no recognized criteria for vehicles of the size pertinent for short haul operation. While the effects of size have been discussed by numerous authors, it appears that a consistent size effects analysis in which the industry and research agencies have complete confidence is unavailable. A number of measures have been taken to develop the necessary solutions, but this work is far from completed. A valid definition of control criteria and handling qualities is essential for the optimum design and operation of short haul V/STOL aircraft. Overall handling qualities is intimately related to data displays to the pilot.

Continuing study of simplification of the data presenting instruments and automatic control systems displays suitable for VTOL operations is required. Automatic approach and flare computing systems for steep or vertical descents would greatly simplify the problems of operating in restricted air space, and might be mandatory in poor weather.

Aerodynamic interference. - The large air masses that are deflected downward around and through V/STOL vehicles create a variety of aerodynamic problems. The interference between airframe and propulsion components, such as the downwash on wings from forward-mounted folding fans, and the upwash from rearward fan locations, has large effects

on hover and transition performance and on handling qualities. The interference between the airframe, the propulsion system, and the ground can result in major lift losses, or increases, due to ground effects. At the present time analytical methods are inadequate for predicting the flow field characteristics resulting from the complex interrelationship of aerodynamic lifting surfaces and the large air masses deflected by the lift propulsion system. A series of wind tunnel tests is recommended to investigate these interrelationships, and to obtain a better understanding of the flow fields involved. The natural fall-out from these studies will result in better techniques for estimating basic stability derivatives, fundamental interference problems, aerodynamic ground effects, ground erosion, reingestion characteristics, and longitudinal force characteristics.

The major difficulty with the investigation of interference problems is the extremely large number of possible vehicle configurations, each with unique problems. In order to contract the general task to one of finite proportion it is recommended that primary emphasis for commercial vehicles be given to propeller and rotor V/STOL aircraft with disc loadings less than 25 pounds per square foot.

Ground Effects. - The problem of ground erosion and reingestion through engines is common to all of the VTOL aircraft and possibly for 1000 foot STOL aircraft. Numerous studies of dust and exhaust gas reingestion have been made, particularly for military aircraft with emphasis on operations on unprepared surfaces. Short haul operations will be made from hard surface runways, which alleviates the ground erosion problem, but not that of hot gas reingestion. Reingestion studies should be expanded to include the effects of hail, slush, and large quantities of water which might be encountered in bad weather.

Airline system study. - The importance of future V/STOL aircraft technology programs will depend in part on the eventual acceptance of short haul service by the public. Although noise is a major factor in this acceptance, convenience is certainly the next most important factor. The potential time savings that are offered by short haul aircraft can be negated by inadequate consideration of other elements of the complete system. Automobile traffic congestion near terminals must be prevented. Similarly investigation of airport and terminal arrangements suitable for V/STOL operations must be made. Aircraft parking, servicing, and the loading and unloading of passengers, mail, and freight, must all be carefully studied. Ground control of V/STOL aircraft is different from that of normal aircraft opera-

tion, since aircraft are maneuvering in a small area and their approaches and landings will be at very short intervals to maintain high passenger flows.

It will be necessary eventually to conduct a thorough airline system simulation study with some emphasis on terminal facilities design, size, and location, and to determine the impact on fare levels of such things as convenience and noise in order to justify intense long-range commercial V/STOL vehicle research programs.

### Final Vehicles

Fan-in-wing STOL and lift/cruise fan VTOL. - These two types have been grouped together because from an R&D standpoint they are primarily propulsion system oriented. The primary problem of this group of STOL and VTOL aircraft is the manifolding of a large number of gas generators into a common duct system. For those designs which manifold the exhaust gases of several jet engines, the problems of synchronizing engine speed, and of gas pressure and temperature should be further examined, especially during transition from one power setting to another. Analog studies by General Electric indicate that this is feasible, but more detailed investigation is required, followed by hardware development.

Means of vectoring fan exit air through larger turning angles at higher efficiencies should receive continued attention. Variable camber cascades or multi-stage cascading show promise of achieving high angles, but many problems remain to be solved. Further configurations that are arranged to provide adequate fuel volume in the wing by use of a multiplicity of small fans behind the rear spar, balanced by thrust vectoring of forward cruise fans, can perhaps allow tilting of the wing fans to obtain efficient flow turning at both inlet and exit. Extremely high values of  $C_{L_{max}}$  which were shown by a sensitivity analysis to be desirable for STOL are obtained with multi-fan engines.

A development problem exists in the design of hot gas ducting to attain infinite fatigue life and/or fail-safe characteristics. Concentric ducting with cooling air directed between the two surfaces may be required, for example. Diverter valve design must be studied in greater detail. The development of valves capable of operating under adverse conditions and after failure of some of the parts is felt to be mandatory for commercial operations. The detail design of lightweight expansion joints required with long gas ducts warrants further study, also a considerable amount of testing to demonstrate the operation

and reliability of these joints. The hot gas control valves and inter-connects with conventional controls and trim devices must be examined for fail-safety and reliability. Some of the more complicated ducting must undergo rigorous testing. The shape, size, and efficiency of elbows in the ducts must be examined in detail so that local hot spots do not develop. Infinite fatigue life of these components is an important problem.

The weight and power required by the reaction control system justifies further study of other methods to achieve control, which should include:

- The use of an inter-burner for occasional peak control power

- Roll control by fan power transfer

- Pitch control by a variable pitch fan

- Yaw control by differential fan exhaust louver deflection

- Separate control engines, particularly for large designs

Jet Flap. - The primary research activity for jet flap aircraft must be to resolve several fundamental problems. It is essential in any discussion of jet flaps to remember that in an inviscid flow any desired lift coefficient, up to a theoretical limit of  $C_L = 4\pi$  (when front and rear stagnation points are coincident), can be obtained by combinations of airfoil shape and flap setting (i.e., camber). Thus, the concept of super-circulation can largely be considered to be the same as that of boundary layer control. This viewpoint is further justified by the fact that at very large blowing flows the additional lift with increased blowing is due almost exclusively to the thrust of the blowing system. These very general considerations allow the aircraft designer much greater latitude in the solution of operational problems than was used in the present study. The use of small values of cold air blowing, or suction, so long as the wing wake is eliminated (inviscid flow) allows practical, long life duct systems to be fitted with wings of reasonable dimensions with little structural compromise. Deflection of the large hot gas flows from STOL thrusting engines, at the engine, will result in more-practical aircraft.

Development is required of pitch trim systems of improved lift efficiency and this can probably be provided by higher by-pass ratio engines with thrust vectoring. Future studies and tests should include large leading edge slats or blown flaps, inter-nacelle leading edge flaps, and canard configurations. A comprehensive series of tests is required with a moving ground plane, over a wide range of wing heights, including ram-wing conditions, to establish the ground interference effects.

Primary emphasis in future work should be on efficient suction and blowing boundary layer control systems that, hopefully, could provide improved performance both in STOL and cruise operation.

Deflected slipstream. - The efficiency of a deflected slipstream configuration depends on the ability of the wing and flap to rotate the slipstream through large angles, approaching 90 degrees for a 1,000 ft. STOL design. Although a large body of data is available on wing flap designs of good efficiency, further investigations both of single and double segment multi-slotted flaps should be made. Low speed wind tunnel programs are suggested, which could include variations in propeller diameter/wing-chord ratio, various propeller locations relative to the wing, and different flap configurations. Both multi-slotted and B.L.C. flaps should be considered.

Tilt Rotor. - This class of vehicle can become an attractive commercial transport when three basic problems are eliminated and future research should be directed to this end. High cruise efficiency can be maintained by use of blade boundary layer control in hover. Such innovations potentially allow  $C_T/\sigma$  to be doubled, which would allow a 30-percent reduction in tip speed without a loss in cruise efficiency. This is a fruitful subject for future research.

The very light disc loading versions of the tilt rotor vehicle concept suffer from an elastic-blade form of whirl flutter at low thrusts and high advance ratios. This phenomena must be investigated theoretically and experimentally to determine flutter boundaries as functions of blade loading and stiffness, and of mounting stiffness and damping. The most fundamental solution to this problem, the use of an integral control gyro to eliminate the cyclic driving forces should also be investigated. Another more complicated solution is mentioned in Reference 16.

The third tilt-rotor problem is that of the inability to make safe emergency landings with the rotors in the cruise position. There are several potential solutions to this problem such as higher disc loading, double-extension landing gears, variable-radius rotors, and pusher configurations. Only the last two are recommended as research areas. The pusher configuration, similar to the Dornier DO-29 STOL airplane, might allow safe emergency landing when the propeller structure is designed to fail progressively by use of composite blade structures. Variable-radius blades are usually thought of as a subject for innovation, rather than research. The number of plausible and feasible concepts that

can satisfy operational requirements and a requirement for minimum development risk are very few and deserve investigation. It should be noted that variable-radius rotors have a favorable effect on all three basic problem areas; propulsive efficiency, whirl-flutter, and emergency landing capability.

Stopped rotor - The study of this class of vehicle should be directed toward drag and weight reductions. Those configurations with exposed rotors could benefit from further research on pylon, hub, and blade drag, including use of boundary layer control on the hub during cruise. The use of blade boundary layer control in hover to double  $C_T/\sigma$  would halve the blade drag in cruise and potentially reduce rotor weight as well. Further research of blade B.L.C. is recommended.

The tilt and stowed rotor vehicles both require propeller like tapering in thickness and planform. This permits operation at higher tip speeds without the accompanying high loss in figure of merit. The stopped rotor figure of merit is not improved noticeably beyond blade twists of about 8 degrees, whereas, the tilt rotor requires blade twists of much higher value to maintain propulsive efficiency in the prop mode.

The weight and complexity of stopped rotor vehicle propulsion systems can be reduced by use of gas-coupled rotor and fan drive systems. This development is particularly attractive for single rotor vehicles because of the elimination of clutches and angle drive gears. Independent drive of the main rotor and tail rotor is also possible in single-rotor vehicles which can potentially allow the tail rotor to stop and be used as a low drag vertical tail surface. The above noted gas-coupled system is very similar to the gas generator manifolding research program for fan-in-wing and lift/cruise fan vehicles and a common general research program is possible.

### Summary

Many interesting and necessary research and development programs have been identified in the present study. There are a few general programs that should be given primary emphasis in future research. The subject of boundary layer control on wings, rotor blades, and hubs is a classic research area and should be exploited fully including development of improved theories based on detailed boundary layer profile measurements including both steady state and transient pressure instrumentation for detection of incipient separation. Manifolding together groups of gas generators to supply groups of turbines is a general engine control research program that supports both fan and rotor vehicle concepts. The subject of noise is of primary importance for commercial aircraft and further

theory-experiment comparisons and community noise simulation experiments are required before short haul systems will become practical. Also further developments in area navigation systems for air traffic control and terminal guidance are required. Before all of the above technological developments can be arranged in a final order of importance it is necessary to conduct airline system simulation studies including ground and air traffic considerations so as to maximize the inherent convenience to the passenger of short haul systems.

## CONCLUSIONS

The design, operational, and economic aspects of several V/STOL and STOL configurations have been evaluated to determine the suitability of the aircraft for use as commercial short haul transports. Within the guidelines and scope of the study, several conclusions are drawn:

1. The order of preference for 1000-foot STOL concepts is:
  1. Deflected Slipstream
  2. Fan-in-Wing
  3. Jet Flap
2. The order of preference for VTOL concepts is:

1. Stowed Rotor	3. Lift/Cruise Fan
2. Tilt Rotor	4. Tilt-Wing
3. It is believed that V/STOL aircraft can operate from a mid-town New York terminal using air space not presently used by conventional aircraft.
4. Although major improvements in all vehicle concepts were made during the study, further worthwhile improvements in terms of reduced gross weights and improved suitability for commercial use are possible by implementation of the design, research, and development studies that have been identified.
5. Certain general research programs have application to many vehicle concepts and these include boundary layer control, control of multiple gas generators on a common manifold, and noise prediction and reduction.
6. Acceptable community noise should be considered a major aircraft design criterion.

Figure 1  
PARAMETRIC STUDY FLOW DIAGRAM

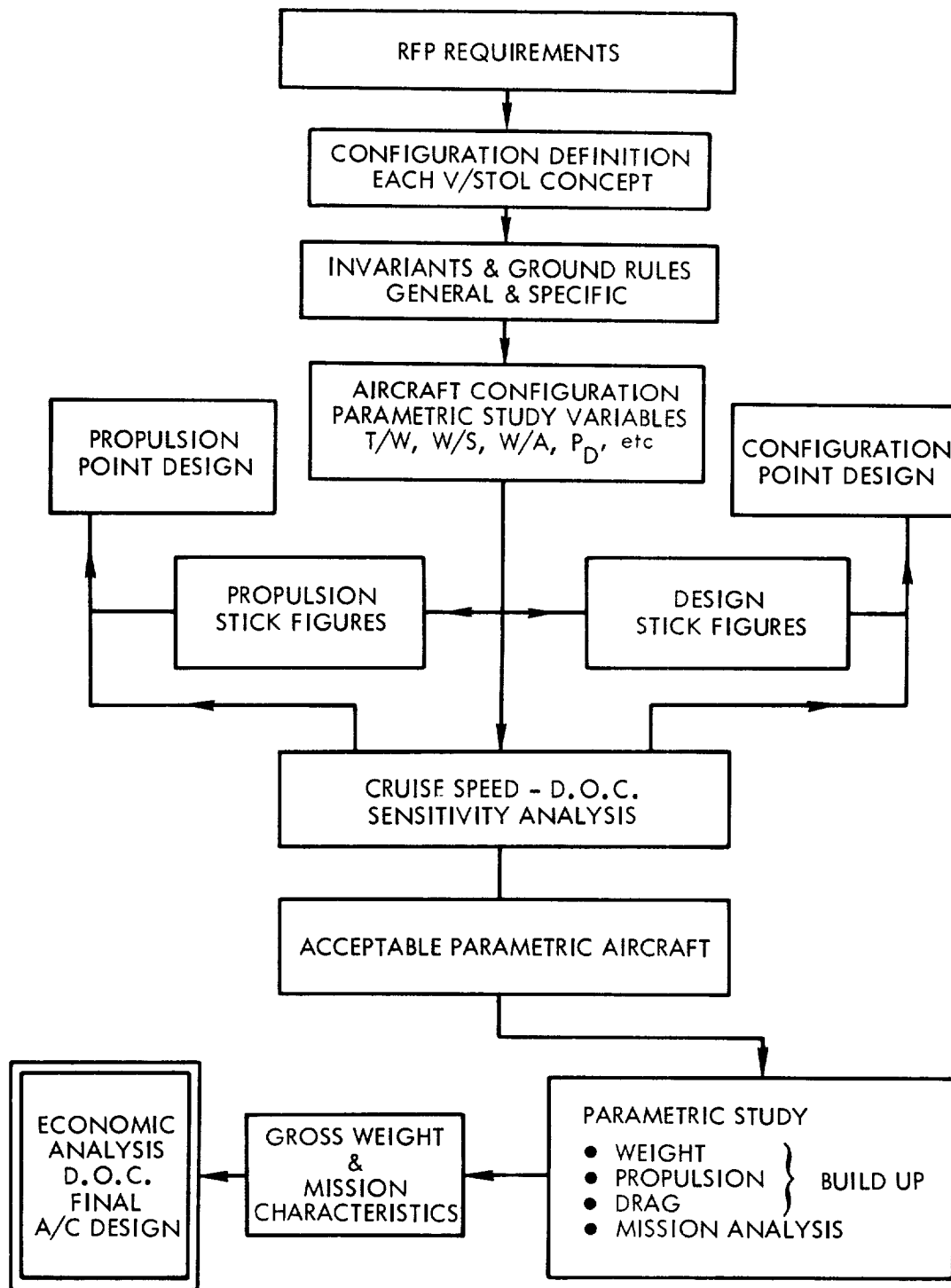


Figure 2  
PARAMETRIC STUDY - BLOCK DIAGRAM - COMPUTER PROGRAMS

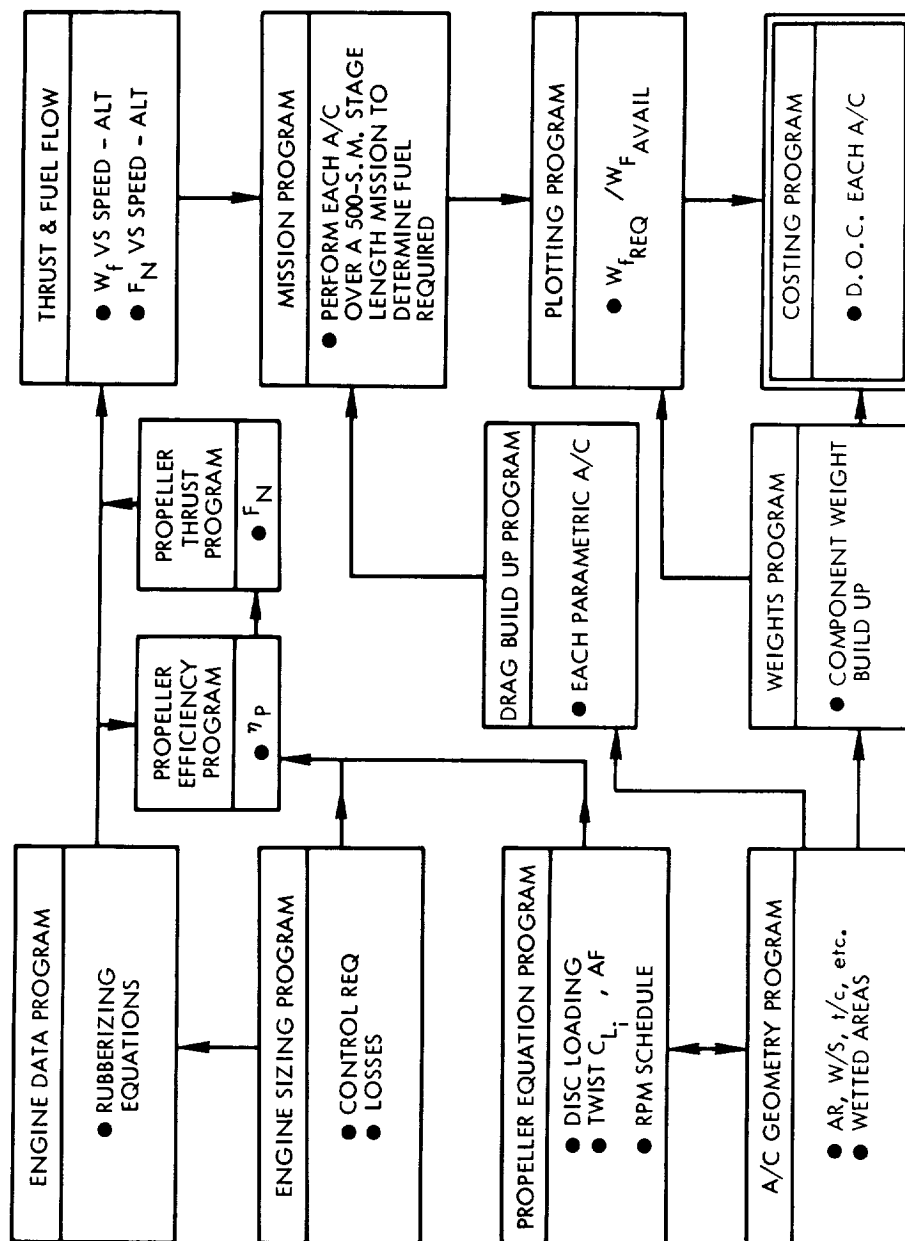


Figure 3-B  
FAN-IN-WING - D.O.C. VS VARIOUS PARAMETERS

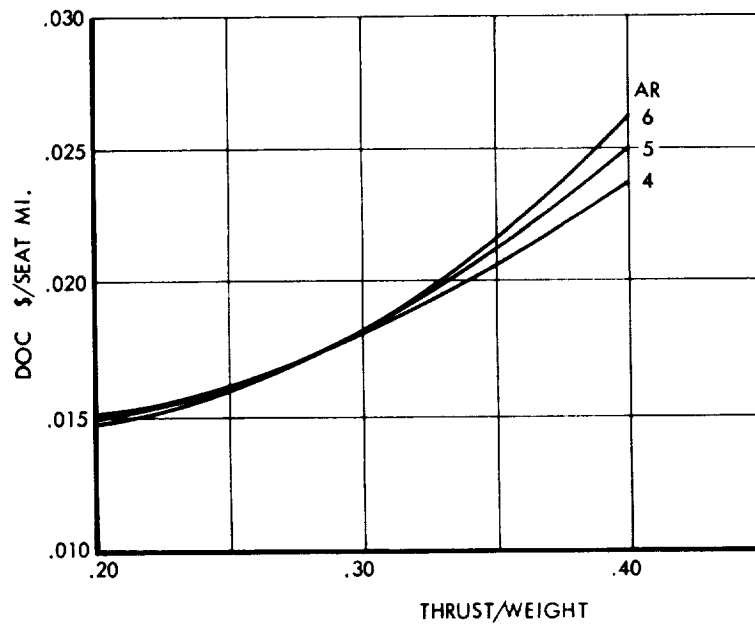
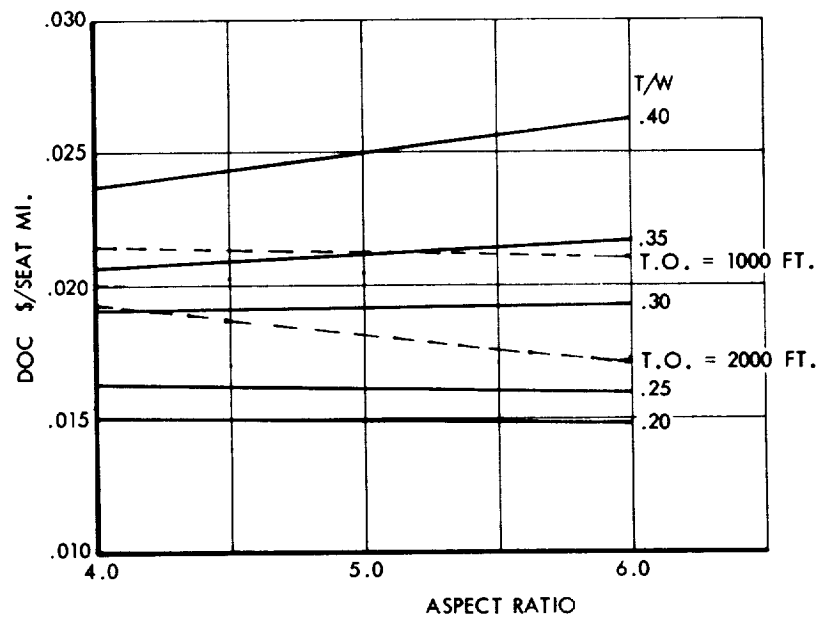


Figure 3-A  
FAN-IN-WING - GROSS WEIGHT VS ASPECT  
AND THRUST/WEIGHT RATIOS

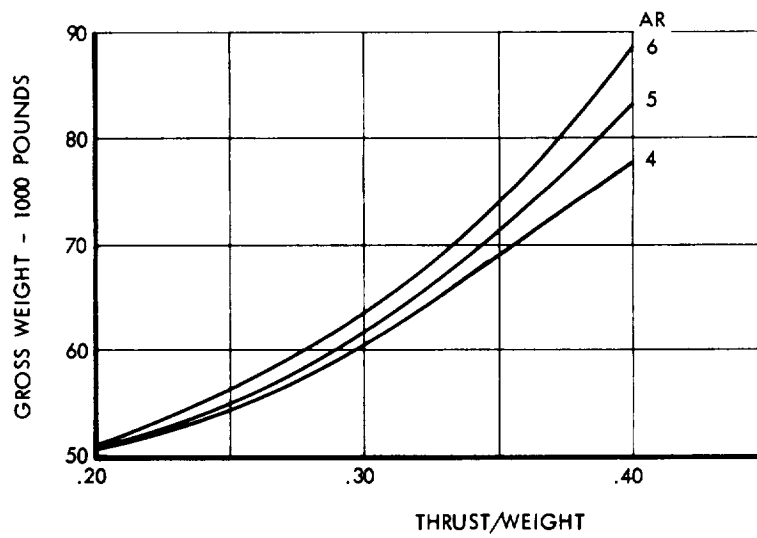
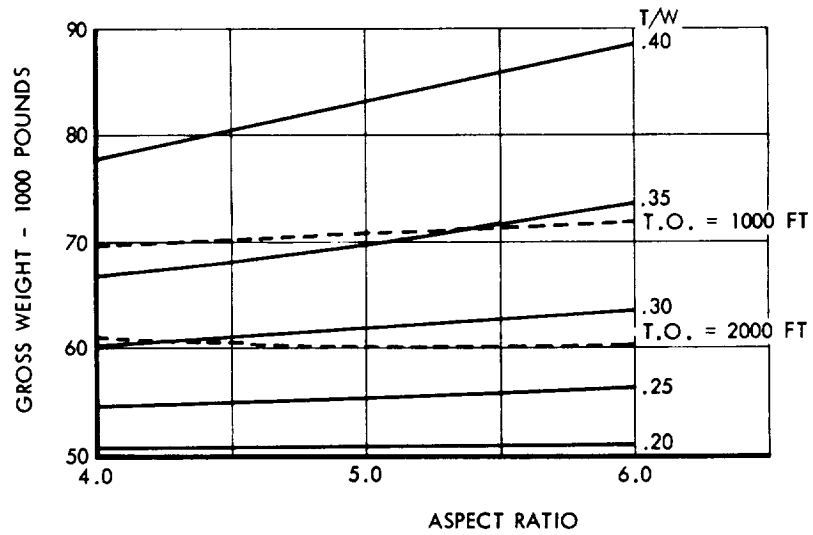


Figure 4  
PARAMETRIC STUDY  
INVARIANTS AND GROUND RULES

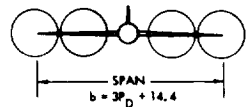
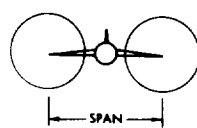
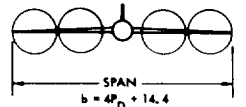
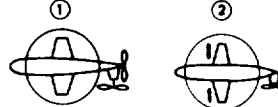





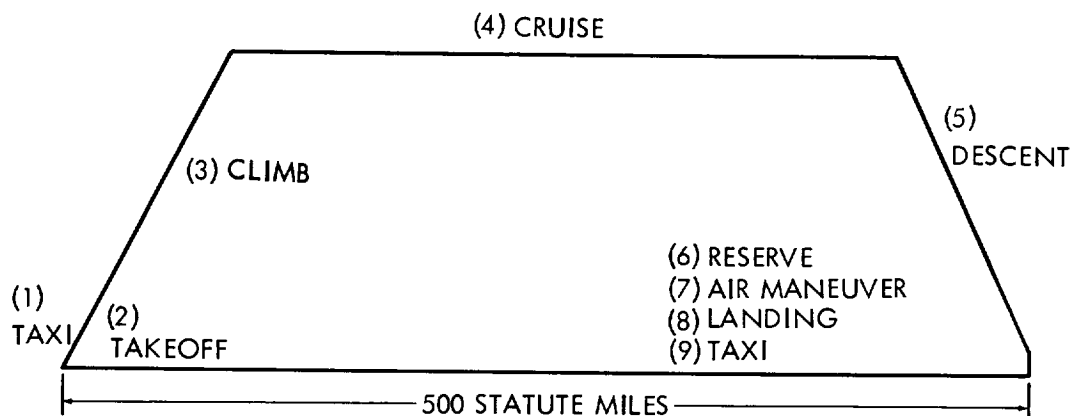
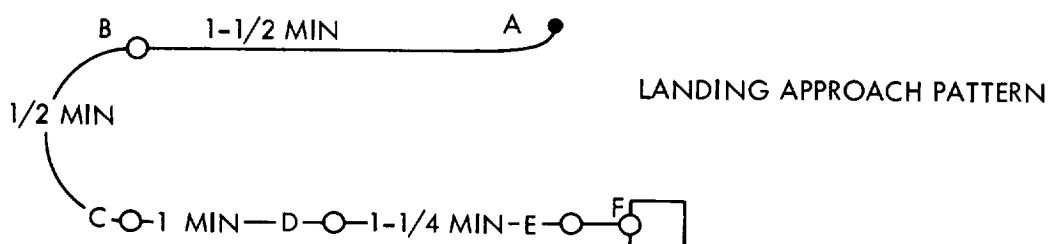
ALL AIRCRAFT	SPECIFIC AIRCRAFT
<p><b>DESIGN</b></p> <ul style="list-style-type: none"> <li>ALL FURNISHING AND EQUIPMENT SAME ALL A/C</li> <li>BAGGAGE - 10 LB/FT<sup>3</sup></li> <li>COMMON FUSELAGE - 60 PASSENGER, 5 ABREAST - 120 PASSENGER, 6 ABREAST</li> <li>DESIGN DIVE SPEED = 1.25 V<sub>CRUISE</sub></li> <li>DESIGN LOAD FACTOR = 2.5g</li> <li>DESIGN SINK RATE = 12 FPS</li> <li>FUSELAGE-PROPELLER CLEARANCE, 2 FT</li> </ul> <p><b>PROPULSION</b></p> <ul style="list-style-type: none"> <li>(4) G.E./1 GAS GENERATORS ALL AIRCRAFT. (LATER MODIFIED TO 6) FOR L/C FAN AIRCRAFT</li> <li>PROPULSION SYSTEM LOSSES AS APPROPRIATE EACH AIRCRAFT</li> <li>CONVENTIONAL PROPELLERS USING HAMILTON STANDARD EFFICIENCIES</li> <li>ROTORS &amp; PROPELLERS <math>C_T/\sigma = 0.12</math></li> </ul> <p><b>WEIGHTS AND STRUCTURES</b></p> <ul style="list-style-type: none"> <li>STATISTICAL WEIGHT EQUATIONS AS APPROPRIATE FOR EACH AIRCRAFT CONCEPT</li> <li>STATE-OF-THE-ART STRUCTURAL TECHNOLOGY</li> </ul> <p><b>STABILITY AND CONTROL</b></p> <ul style="list-style-type: none"> <li>STABILITY AND CONTROL REQUIREMENTS</li> <li>CONVENTION CONTROL SURFACES IN CRUISE MODE</li> <li>LANDING APPROACH - SPEED RULE - STALL MARGIN OF <math>\Delta V = 10</math> KNOTS AND <math>\Delta\alpha = 10^\circ</math> (STOL AIRCRAFT)</li> </ul> <p><b>PERFORMANCE</b></p> <ul style="list-style-type: none"> <li>ENGINES SIZED FOR 86° S. L. HOT DAY (3) ENGINES OPERATIVE CONDITION. ENGINE OUT OVERSPEED OF 10% INCREASE IN SHAFT HORSEPOWER OR THRUST ON REMAINING (3) ENGINES</li> <li>SKIN FRICTION DRAG COEFFICIENT (0.0035 TURBOPROP AIRCRAFT - 0.0032 TURBOFAN AIRCRAFT)</li> <li>PARASITE DRAG</li> <li>COMPRESSIBILITY DRAG</li> <li>DESIGN MISSION 500 S. M.</li> </ul> <ul style="list-style-type: none"> <li>CONVENTIONAL CONTROLS IN CRUISE - LOW SPEED - SEE SPECIFIC AIRCRAFT</li> <li>ALL FUEL IN WINGS</li> <li>MINIMUM WING <math>l/c</math> TO ACCOMMODATE FUEL</li> <li>CABIN PRESSURIZATION</li> <li>CROSS SHAFTING ALL PROPELLER OR ROTOR AIRCRAFT</li> <li>GAS COUPLING ALL TURBOFAN AIRCRAFT</li> <li>(4) PROPELLER BLADES</li> <li>PROPELLER TIP SPEED - SEE SPECIFIC AIRCRAFT</li> <li>ROTOR TIP SPEED - 700 FT/SEC</li> <li>ENGINE COMPONENT EFFICIENCIES CONSTANT</li> <li>MODIFIED G. E./1 ENGINE WEIGHT EQUATIONS</li> <li>CABIN PRESSURIZED TO 8000 FT @ CRUISE ALTITUDE - 25,000 FT</li> <li>GUST LOAD FACTOR PER F. A. R. PART 25</li> </ul>	<p><b>TILT WING</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 0^\circ</math></li> <li><math>\lambda = 0.60</math></li> <li><math>l/c = 16\%R</math> to <math>14\%T</math></li> </ul>  <p><b>TILT ROTOR</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 0^\circ</math></li> <li><math>\lambda = 0.60</math></li> <li><math>l/c = 16\%R</math> to <math>14\%T</math></li> </ul>  <p><b>DEFLECTED SLIPSTREAM</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 0^\circ</math></li> <li><math>\lambda = 0.70</math></li> <li><math>l/c = 15\%R</math> to <math>13\%T</math></li> </ul>  <p><b>STOPPED ROTOR</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 0^\circ</math></li> <li><math>\lambda = 0.60</math></li> <li><math>l/c = 14\%R</math> to <math>12\%T</math></li> </ul>  <p><b>LIFT FAN-CRUISE FAN</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 25^\circ</math></li> <li><math>\lambda = 0.40</math></li> <li><math>l/c = 13\%R</math> to <math>10\%T</math> (ORIG)   <math>10\%T</math> (FINAL)</li> <li>DISTANCE BETWEEN C. G. AND CRUISE ENGINES A VARIABLE</li> </ul>  <p><b>FAN-IN-WING</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 25^\circ</math></li> <li><math>\lambda = 0.40</math></li> <li><math>l/c = 13\%</math></li> <li>WING AREA (f) OF FAN DIAMETER</li> </ul>  <p><b>JET FLAP</b></p> <ul style="list-style-type: none"> <li><math>\Delta c/4 = 25^\circ</math></li> <li><math>\lambda = 0.40</math></li> <li><math>l/c = (f) AR \times W/S</math> &amp; <math>T/W</math></li> </ul>  <p><b>NOSE JET FOR GLIDE PATH CONTROL AND PITCH TRIM</b></p>  <p><b>ENGINE LOUVERS FOR GLIDE PATH CONTROL AND PITCH TRIM</b></p> 

Figure 5  
DESIGN FLIGHT PROFILE



- (1) TWO MINUTES @ TAXI PWR ALL ENGINES. THRUST ASSUMED 2% T.O.G.W.  
 (2) ONE MINUTE @ T.O. PWR ALL ENGINES. NO DISTANCE CREDIT  
 (3) CLIMB ON COURSE @ N.R.P. @ SPEED TO MINIMIZE D.O.C.  
 (4) CRUISE @ ALTITUDE AND SPEED TO MINIMIZE D.O.C.  
 (5) DESCENT TO 1000 FT @ SPEED AND PWR TO MINIMIZE D.O.C.  
 (6) 1. RESERVE - 30-MIN HOLD @ 5000 FT @ 1.05 MIN DRAG. NO DIST. CREDIT



2. A TO D @ APPROACH PWR & SPEED. NO CREDIT-TIME OR DISTANCE  
 3. D TO E @ APPROACH PWR & SPEED. NO CREDIT-TIME OR DISTANCE  
 4. E TO A @ TAKE-OFF PWR. NO CREDIT-TIME OR DISTANCE  
 (7) AIR MANEUVER (REPEAT ITEM (6) 2 & 3)  
 (8) LANDING - ONE MINUTE @ LANDING PWR - E TO F  
 (9) TAXI - TWO MINUTES @ TAXI PWR

POINT	ALT	SPEED		TIME	} CONDITIONS FOR LANDING APPROACH PATTERN
		STOL	VTOL		
A	1000	80	80	1 1/2	
B	1000	80	80	1 1/2	
C	1000	80	80	1	
D	1000	60	45	1 1/4	
E	100	60	45	1	
F	0	60	0	1	

Figure 6A  
PARAMETRIC STUDY CONFIGURATION VARIABLES

VARIABLE A/C CONCEPT	GROSS WEIGHT 1000 LB	ASPECT RATIO AR	WING LOADING W/S - LB/FT <sup>2</sup>	DISC LOADING W/A - LB/FT <sup>2</sup>	PROP/ROTOR DIAMETER P <sub>D</sub> - FT	THRUST TO WEIGHT T/W (4)
JET FLAP	45, 60, 75	4, 6, 8	60, 80, 100	—	—	.2, .4, .6, .8
FAN-IN-WING	55, 65, 75	4, 5, 6, 7 8, 9, 10	(1)	(3)	—	.2, .3, .4
DEFLECTED S. S.	45, 50, 55 60, 65	4, 6, 8	(2)	—	12, 14, 16	.4, .6, .8
LIFT/CRUISE FAN	55, 65, 75	4, 6, 8	40, 80, 120	(3)	—	(5)
TILT ROTOR	60, 70, 80	4, 5, 6	(2)	—	40, 50, 60	(5)
TILT WING	60, 70, 80	4, 6, 8	(2)	—	16, 18, 20 22, 24	(5)
STOPPED ROTOR	60, 70, 80	8	120	7, 11, 15	18, 22, 26	(5)

NOTES: (1) WING AREA (F) FAN DIAMETER

(2) WING AREA (F) SPAN RULES (SEE FIGURE 4)

(3) FAN DISC LOADING (F) FAN DIAMETER AND G. W.

(4)  $T/W = \text{THRUST} = \frac{\text{INSTALLED S. L. STATIC @ 86° F (ALL GAS GENERATORS)}}{G. W.}$   
T.O. G. W.

(5) T/W AS DEFINED BY REQUIREMENTS

Figure 6B

## PARAMETRIC STUDY CONFIGURATION VARIABLES

A/C CONCEPT	GROSS WEIGHT (1000 LB)	ASPECT RATIO	WING LOADING W/S (LB/FT <sup>2</sup> )	DISK LOADING (LB/FT <sup>2</sup> )	PROP DIAMETER (FT)	ROTOR TIP SPEED (FT/SEC)	THRUST TO WEIGHT T/W	YAW ACCELL REQUIREMENT
SINGLE STOWED ROTOR PROP	65, 75, 85	6	80, 100, 120	7, 11, 15	14, 16, 18	700 800 900	①	①
SINGLE STOWED ROTOR JET	65, 75, 85	6	80, 100, 120	7, 11, 15		700 800 900	①	①
TWIN TRAILED ROTOR PROP	65, 75, 85	4, 6, 8	-	7, 11, 15	14, 16, 18	700 800 900	①	①
TWIN TRAILED ROTOR JET	65, 75, 85	4, 6, 8	-	7, 11, 15		700 800 900	①	①
TILT ROTOR	65, 75, 85	6	-	-	46, 56, 66	700 800 900	①	①

① DEFINED BY CONTRACT REQUIREMENTS

Figure 7

SHORT HAUL TRANSPORT CONCEPT DEVELOPMENTS  
(60 PASSENGER)

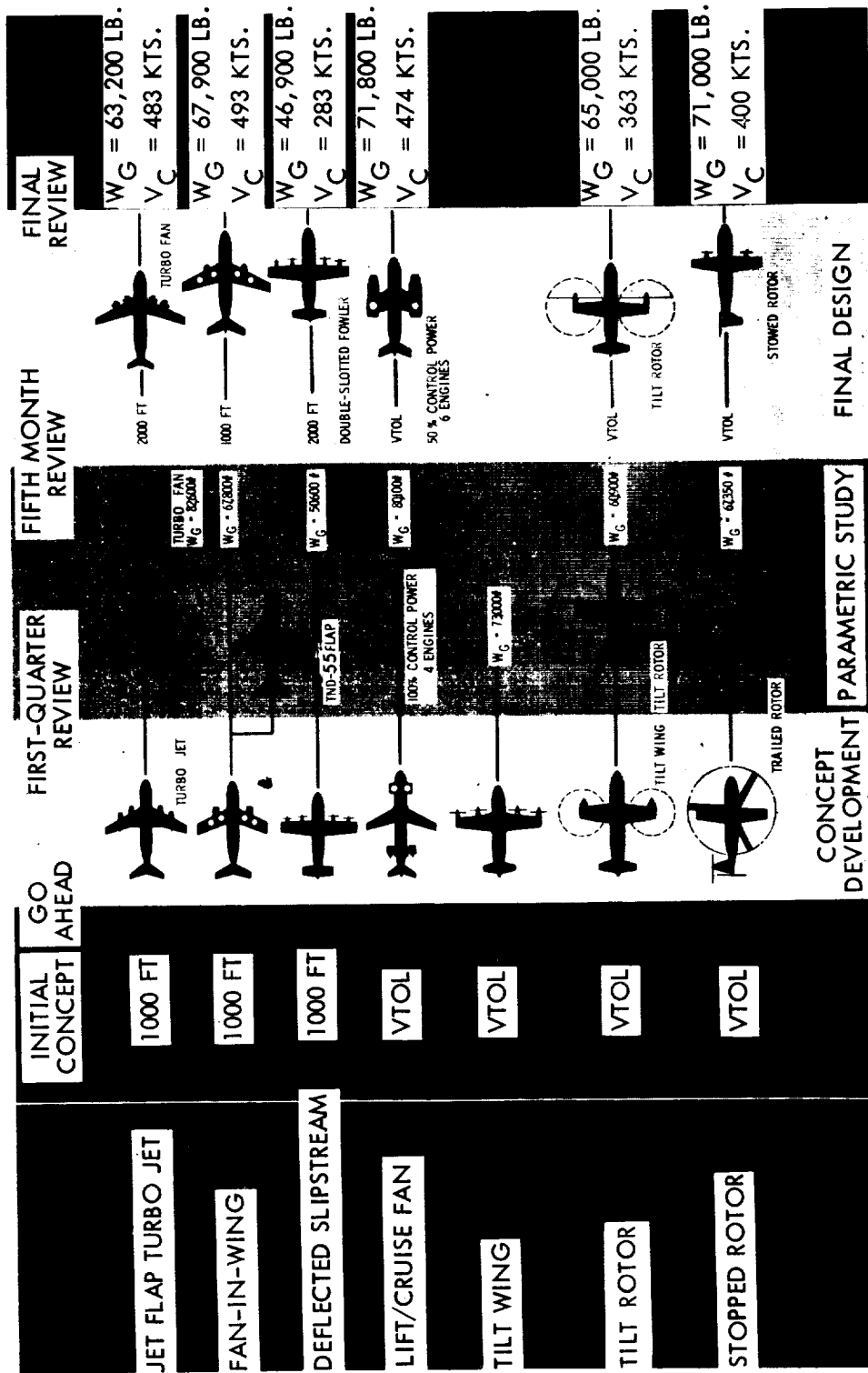


Figure 8  
PHYSICAL CHARACTERISTICS OF SELECTED AIRCRAFT IN FINAL CONFIGURATION -  
60 PASSENGERS

Aircraft Type	W <sub>g</sub> pounds	AR	$\Delta c/4$ degrees	$\lambda$	t/c Root	t/c Tip	S sq ft	W/S lb/sq ft	b feet
Tilt rotor - VTOL	65000	6	0	.60	.16	.14	835	78	71
Lift/cruise fan - VTOL	71800	3	25	.60	.13	.13	798	90	49
Stopped rotor - VTOL	71000	6	0	.60	.14	.12	592	120	60
Deflected slipstream - STOL 2000'	46900	6	0	.70	.15	.13	832	56	71
Jet flap - STOL 2000'	63200	8	25	.40	.13	.10	843	75	82
Fan-in-wing - STOL 1000'	67900	6	25	.44	.13	.11	1069	64	80

Aircraft Type	P <sub>D</sub> feet	W/A lb/sq ft	T/W	T/Eng pounds	SHP/ Eng.	F <sub>D</sub> (lift) inches	F <sub>D</sub> (cruise) inches	S <sub>H</sub> sq ft	S <sub>V</sub> sq ft
Tilt rotor - VTOL	56	13	1.28	-	3840	-	-	237	122
Lift/cruise fan - VTOL	-	-	1.34	7300	-	85	65	200	153
Stopped rotor - VTOL	16*	13	1.28	-	4350	-	-	63	104
Deflected slipstream - STOL 2000'	14	-	.47	-	1275	-	-	237	211
Jet flap - STOL 2000'	-	-	.40	6800	-	-	-	125	172
Fan-in-wing - STOL 1000'	-	-	.35	6488	-	55	-	330	293

\*Rotor diameter 83.4 ft

Figure 9

PHYSICAL CHARACTERISTICS OF SELECTED AIRCRAFT  
IN FINAL CONFIGURATION — 120 PASSENGERS

Aircraft Type	$W_g$ lb	AR	$\Delta \varepsilon/4$ Degrees	$\lambda$	t/c Root	t/c Tip	S sq ft	W/S lb/sq ft	b feet
Tilt rotor — VTOL	123500	6	0	.60	.16	.14	1495	83	95
Lift/cruise fan — VTOL	141600	3	25	.60	.13	.13	1573	90	69
Deflected slipstream— STOL 2000 ft	86400	6	0	.70	.15	.13	1533	56	96
Jet flap — STOL 2000 ft	120000	8	25	.40	.13	.10	1600	75	113
Fan-in-wing — STOL 1000 ft	124000	6	25	.43	.13	.11	1865	67	106

Aircraft Type	$P_D$ feet	W/A lb/sq ft	T/W	T/Eng lb	SHP/ Eng.	$F_D$ (lift) inches	$F_D$ (cruise) inches	$S_H$ sq ft	$S_V$ sq ft
Tilt rotor — VTOL	78	13	1.30	-	7100	-	-	495	223
Lift/cruise fan — VTOL	-	-	1.51	16370	-	125	95	293	224
Deflected slipstream— STOL 2000 ft	20	-	.47	-	2265	-	-	560	243
Jet flap — STOL 2000 ft	-	-	.40	12670	-	-	-	262	263
Fan-in-wing — STOL 1000 ft	-	-	.35	11840	-	73	-	543	406

Figure 10 500 STATUTE MILE RANGE PERFORMANCE FOR FINAL SELECTED CONFIGURATIONS

60 Passenger Vehicles	W <sub>f</sub> Pounds	W <sub>f</sub> Block Pounds	V <sub>Cruise</sub> Knots	V <sub>Block</sub> MPH	T <sub>Block</sub> Hours	L/D Cruise	C <sub>D</sub> Cruise	F <sub>N</sub> Cruise Pounds	η <sub>p</sub> Cruise	Fig. of Merit	h <sub>p</sub> Cruise Feet	D.O.C. c/seat mi.
Tilt rotor - VTOL	6400	4350	363	341	1.47	13.6	.0275	4600	.765	.69	25000	2.67
Lift/cruise fan - VTOL	11547	7788	474	409	1.22	9.3	.0325	7720	-	-	30520	2.87
Stopped rotor - VTOL	7940	6260	400	359	1.39	12.7	.0309	5300	.85	.69	20000	2.65
Deflected slipstream - STOL 2000'	3220	2408	283	281	1.78	13.5	.0239	3470	.92	-	15280	1.96
Jet flap - STOL 2000'	9875	7294	483	424	1.18	7.7	.0320	8210	-	-	31000	2.26
Fan-in-wing - STOL 1000'	13980	10640	493	440	1.14	6.6	.0286	10290	-	-	30000	2.67
120 Passenger Vehicles												
Tilt rotor - VTOL	11640	7690	390	344	1.45	13.4	.0268	8500	.765	.69	25000	2.01
Lift/cruise fan - VTOL	22900	15210	480	409	1.22	9.5	.0370	14910	-	-	35000	2.36
Deflected slipstream - STOL 2000'	5775	4340	282	279	1.79	13.6	.0235	6350	.92	-	14718	1.47
Jet flap - STOL 2000'	18340	13910	489	425	1.17	7.7	.0313	15580	-	-	31000	1.77
Fan-in-wing - STOL 1000'	25170	19130	498	444	1.13	6.6	.0270	18790	-	-	30000	2.04

Figure 11  
500 MILE RANGE SEGMENT FUEL IN POUNDS FOR FINAL SELECTED CONFIGURATIONS

60 Passenger Vehicles	Taxi	Take-off	Climb	Cruise	Descent	Air Maneuver	Landing	Taxi	Reserve
Tilt rotor - VTOL	63	121	1221	1980	309	472	121	63	2050
Lift/cruise fan - VTOL	90	641	2290	2643	393	1000	641	90	3759
Stopped rotor - VTOL	72	138	1612	3454	315	459	138	72	1680
Deflected slipstream - STOL 2000'	19	38	546	1560	63	130	33	19	812
Jet flap - STOL 2000'	123	284	1515	3996	569	400	284	123	2581
Fan-in-wing - STOL 1000'	90	386	1900	6711	208	940	315	90	3340
120 Passenger Vehicles									
Tilt rotor - VTOL	114	223	2005	3700	551	791	192	114	3950
Lift/cruise fan - VTOL	206	1455	3989	4598	1401	1900	1455	206	7690
Deflected slipstream - STOL 2000'	33	68	971	2829	108	240	58	33	1435
Jet flap - STOL 2000'	241	562	2778	7569	1257	700	562	241	4430
Fan-in-wing - STOL 1000'	165	698	3287	12149	409	1680	577	165	6040

Figure 12

GENERAL ARRANGEMENT  
60 PASSENGER  
DEFLECTED SLIPSTREAM STOL

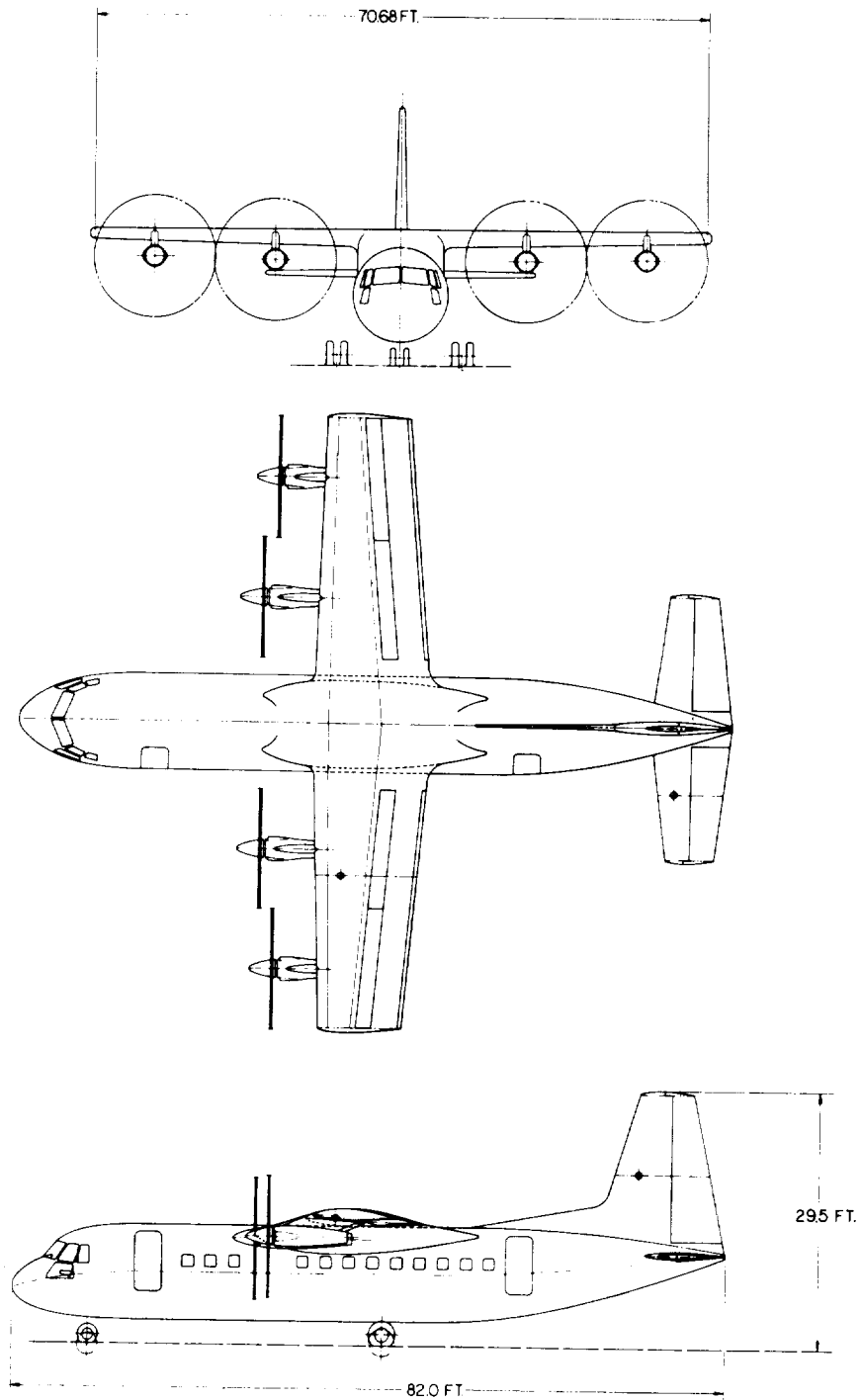


Figure 13

GENERAL ARRANGEMENT  
120 PASSENGER  
DEFLECTED SLIPSTREAM STOL

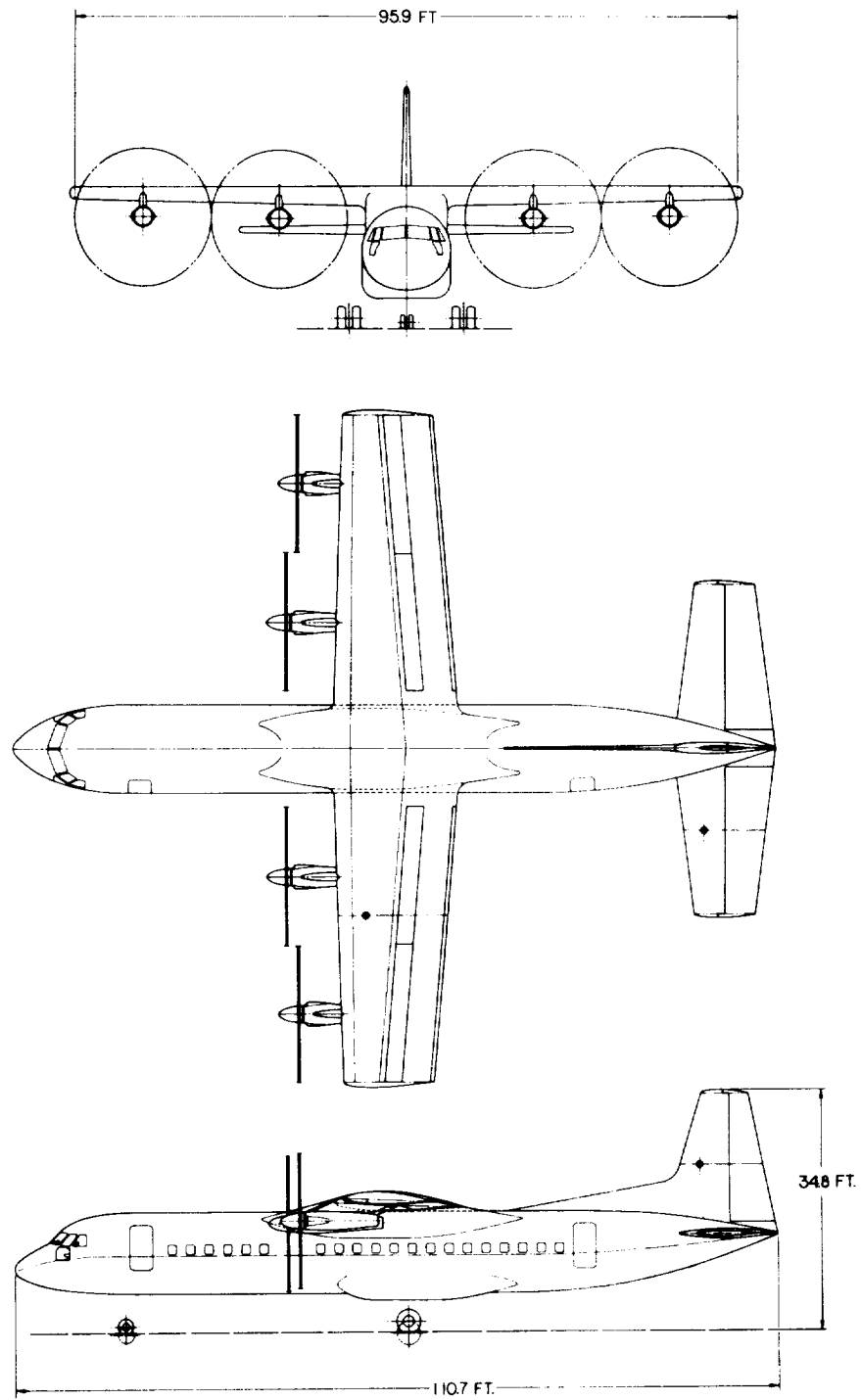


Figure 14

PROPULSION SYSTEM SCHEMATIC - DEFLECTED SLIPSTREAM STOL

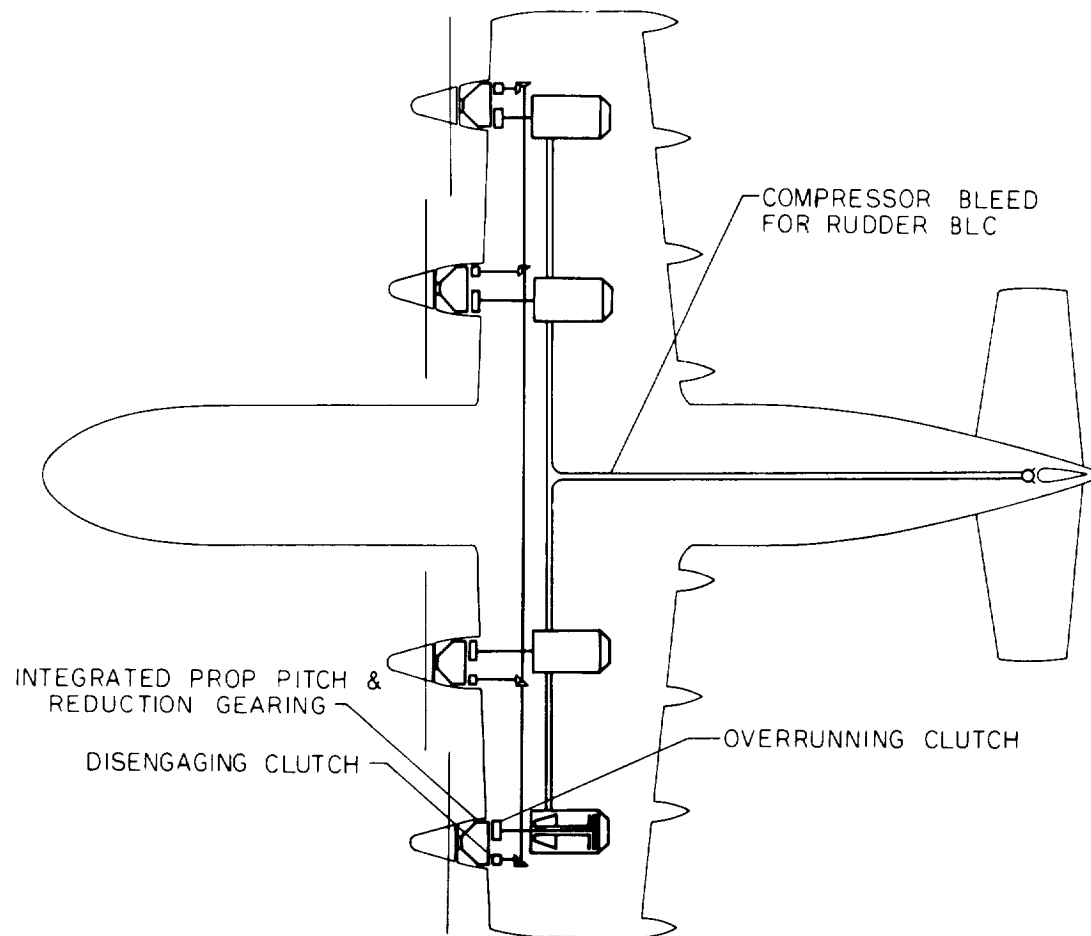


Figure 15

DEFLECTED SLIPSTREAM - WEIGHT STATEMENTS - FINAL SELECTED DESIGNS  
(pounds)

	<u>60 Passenger</u>	<u>120 Passenger</u>
WING	4,630	10,220
EMPENNAGE	1,320	2,360
FUSELAGE	5,310	9,590
LANDING GEAR	1,750	3,335
SURFACE CONTROLS	1,280	1,595
HYDRAULICS	400	545
INSTRUMENTS	420	485
ELECTRICAL	950	1,800
ELECTRONICS	850	1,100
FURNISHINGS AND EQUIPMENT	4,925	9,160
AIR CONDITIONING AND ANTI-ICING	1,025	1,910
AUXILIARY POWER UNIT	345	385
NACELLES	1,085	1,685
PROPULSION	5,300	8,690
WEIGHT EMPTY	29,590	52,860
CREW	520	660
MISCELLANEOUS USEFUL LOAD	260	510
ENGINE OIL	60	110
UNUSABLE FUEL	50	85
OPERATING WEIGHT	30,480	54,225
PAYLOAD	13,200	26,400
ZERO FUEL WEIGHT	43,680	80,625
USABLE FUEL	3,220	5,775
GROSS WEIGHT	46,900 pounds	86,400 pounds

Figure 16

DEFLECTED SLIPSTREAM 2000-FOOT STOL STABILITY AND CONTROL SUMMARY  
Maximum Gross Weight, C.G. at 25 percent MAC

<u>Takeoff Configuration V = 68 Knots, 100% Power</u>	<u>Unit</u>	<u>60-Passenger</u>	<u>120-Passenger</u>
Directional Control Power	rad/sec <sup>2</sup>	0.39	0.19
Directional Stability	1/sec <sup>2</sup>	0.42	0.195
Directional Damping	1/sec	-0.36	-0.31
Pitch Control Power	rad/sec <sup>2</sup>	0.40	0.32
<u>Landing Configuration V = 86 Knots, 50% Power</u>			
Directional Control Power	rad/sec <sup>2</sup>	0.54	0.26
Directional Stability	1/sec <sup>2</sup>	0.58	0.27
Directional Damping	1/sec <sup>2</sup>	-0.29	-0.24
Pitch Control Power	rad/sec <sup>2</sup>	0.425	0.37
Dihedral Effect, Zero Geometric Dihedral	1/sec <sup>2</sup>	-2.2	-1.8
Roll Damping	1/sec	-0.50	-0.61
Pitch Damping Ratio at Maximum Weight for C.G. at 31.5 Percent MAC		0.31	0.30

Figure 17  
EFFECT OF CROSS SHAFTING ON  
GROSS WEIGHT VS TAKEOFF DISTANCE

DEFLECTED SLIPSTREAM STOL  
SEA LEVEL 86°F

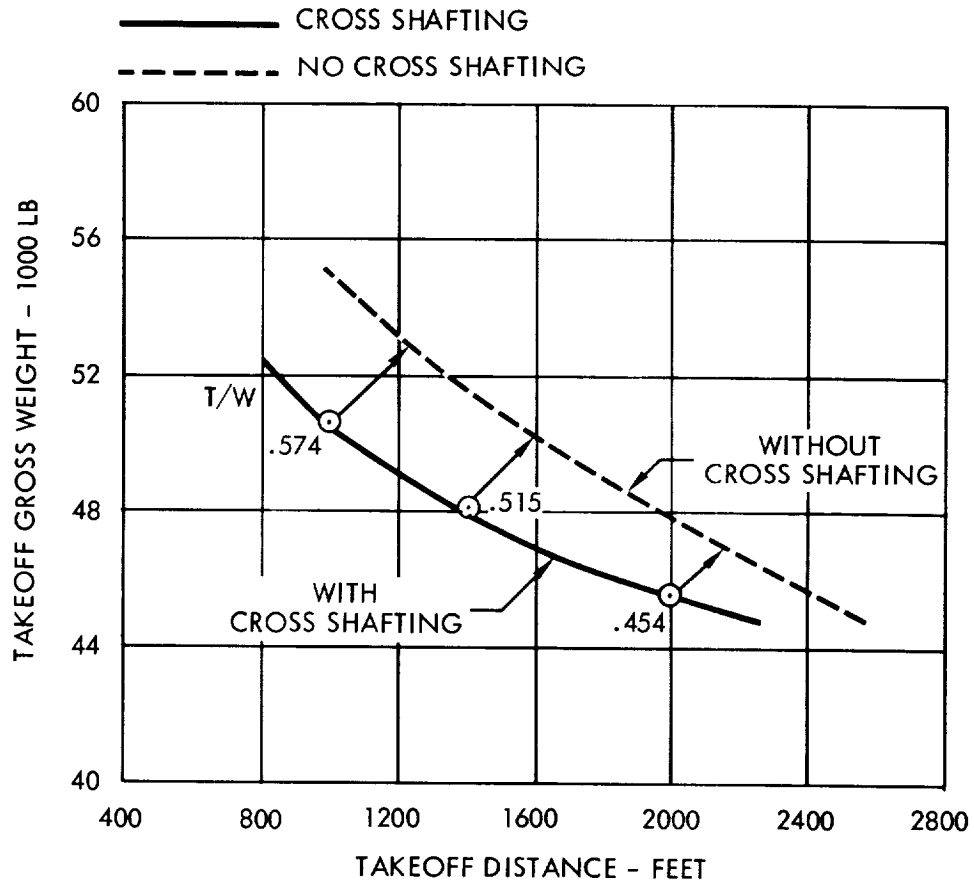


Figure 18

GENERAL ARRANGEMENT  
60 PASSENGER  
JET FLAP STOL

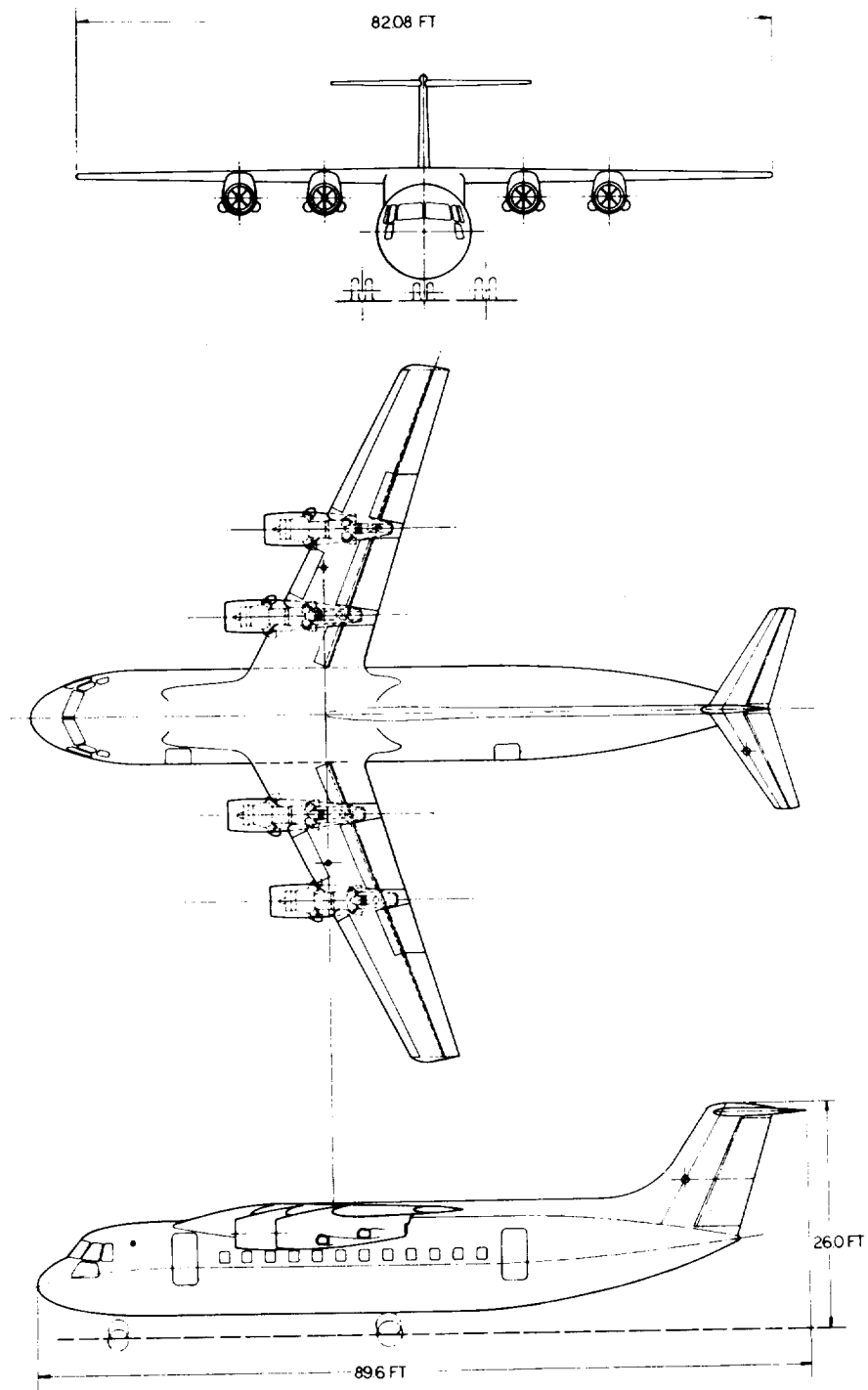


Figure 19

GENERAL ARRANGEMENT  
120 PASSENGER  
JET FLAP STOL

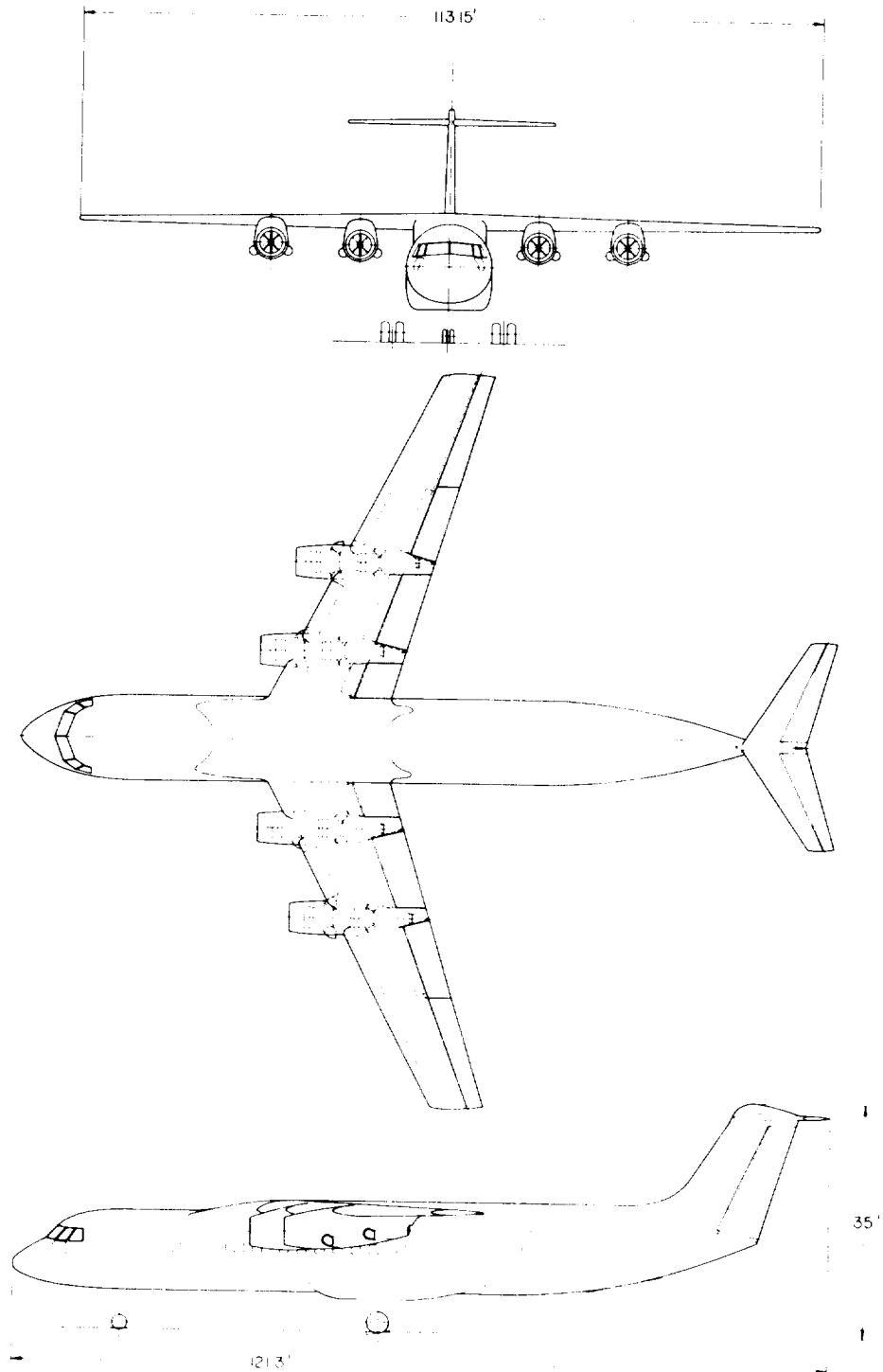


Figure 20  
PROPULSION SYSTEM SCHEMATIC - JET FLAP STOL

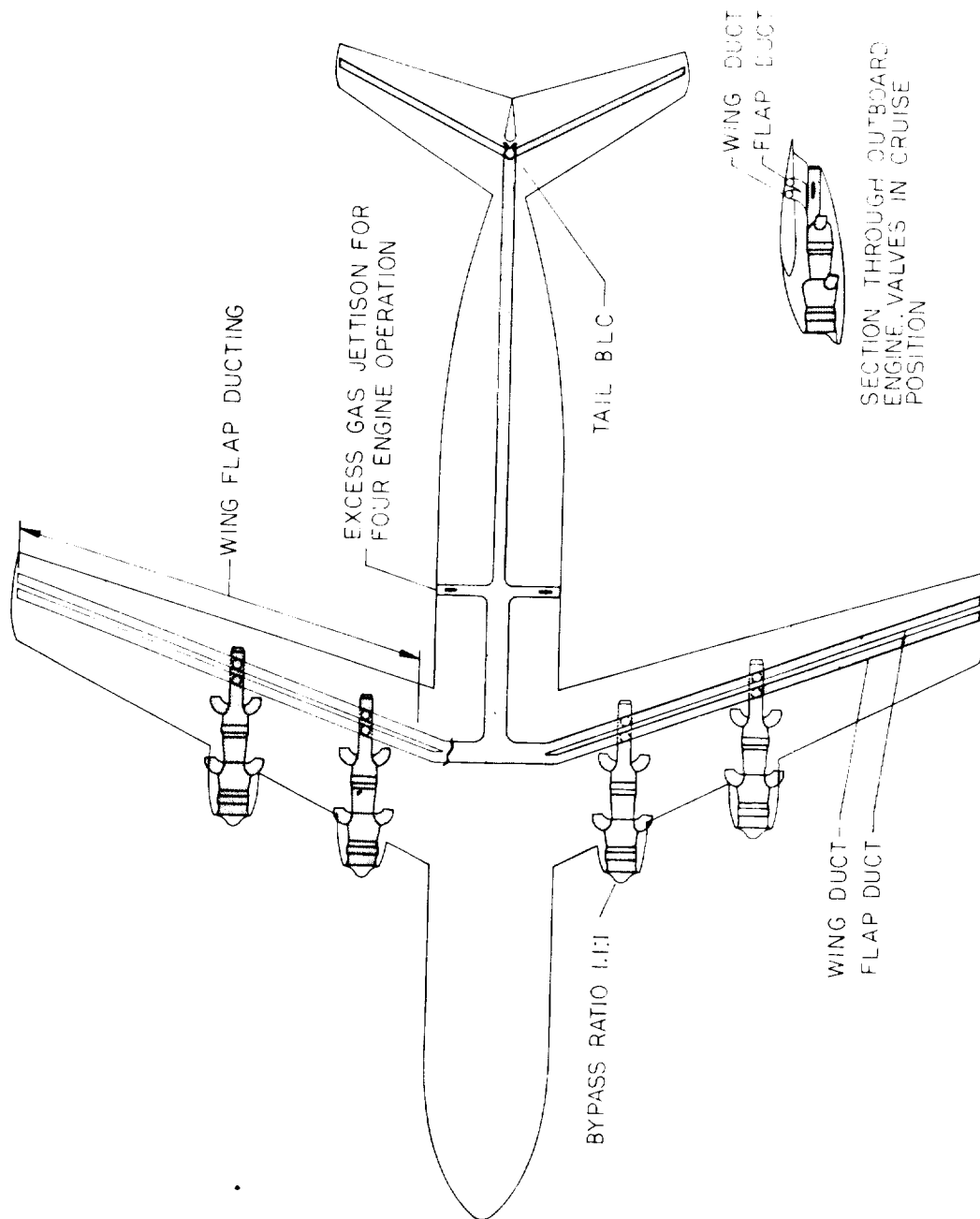


Figure 21

JET FLAP STOL (2000 FT) - WEIGHT STATEMENTS - FINAL SELECTED DESIGNS  
(pounds)

	<u>60 Passenger</u>	<u>120 Passenger</u>
WING	7,520	17,760
EMPENNAGE	1,510	2,710
FUSELAGE	6,700	12,860
LANDING GEAR	2,400	4,745
SURFACE CONTROLS	1,510	1,935
HYDRAULICS	440	605
INSTRUMENTS	430	505
ELECTRICAL	950	1,800
ELECTRONICS	850	1,100
FURNISHINGS AND EQUIPMENT	5,070	9,365
AIR CONDITIONING AND ANTI-ICING	1,575	3,070
AUXILIARY POWER UNIT	360	420
NACELLES	2,110	3,460
PROPULSION	7,660	13,275
	<hr/>	<hr/>
WEIGHT EMPTY	39,085	73,610
CREW	520	660
MISCELLANEOUS USEFUL LOAD	260	510
ENGINE OIL	110	205
UNUSABLE FUEL	150	275
	<hr/>	<hr/>
OPERATING WEIGHT	40,125	75,260
PAYLOAD	13,200	26,400
	<hr/>	<hr/>
ZERO FUEL WEIGHT	53,325	101,660
USABLE FUEL	9,875	18,340
	<hr/>	<hr/>
GROSS WEIGHT	63,200 pounds	120,000 pounds

Figure 22

JET FLAP STOL (2000-FOOT) STABILITY AND CONTROL SUMMARY

Landing Configuration, Maximum Gross Weight, CG at 25 percent MAC, V = 86 Knots  
No Stability Augmentation System

	<u>Unit</u>	<u>60-Passenger</u>	<u>120-Passenger</u>
Directional Control Power	rad/sec <sup>2</sup>	0.47	0.29
Directional Stability	1/sec <sup>2</sup>	0.93	0.74
Directional Damping	1/sec	-0.28	-0.40
Pitch Control Power	rad/sec <sup>2</sup>	0.60	0.52
Dihedral Effect, Zero Geometric Dihedral	1/sec <sup>2</sup>	-2.04	-1.55
Roll Damping	1/sec	-0.67	-0.73
Roll Control Power	rad/sec <sup>2</sup>	0.48	0.37
Pitch Damping Ratio at Maximum Weight Applicable to a C.G. at 31.5 Percent MAC		0.29	0.35

Figure 23

GENERAL ARRANGEMENT  
60 PASSENGER  
FAN-IN-WING STOL

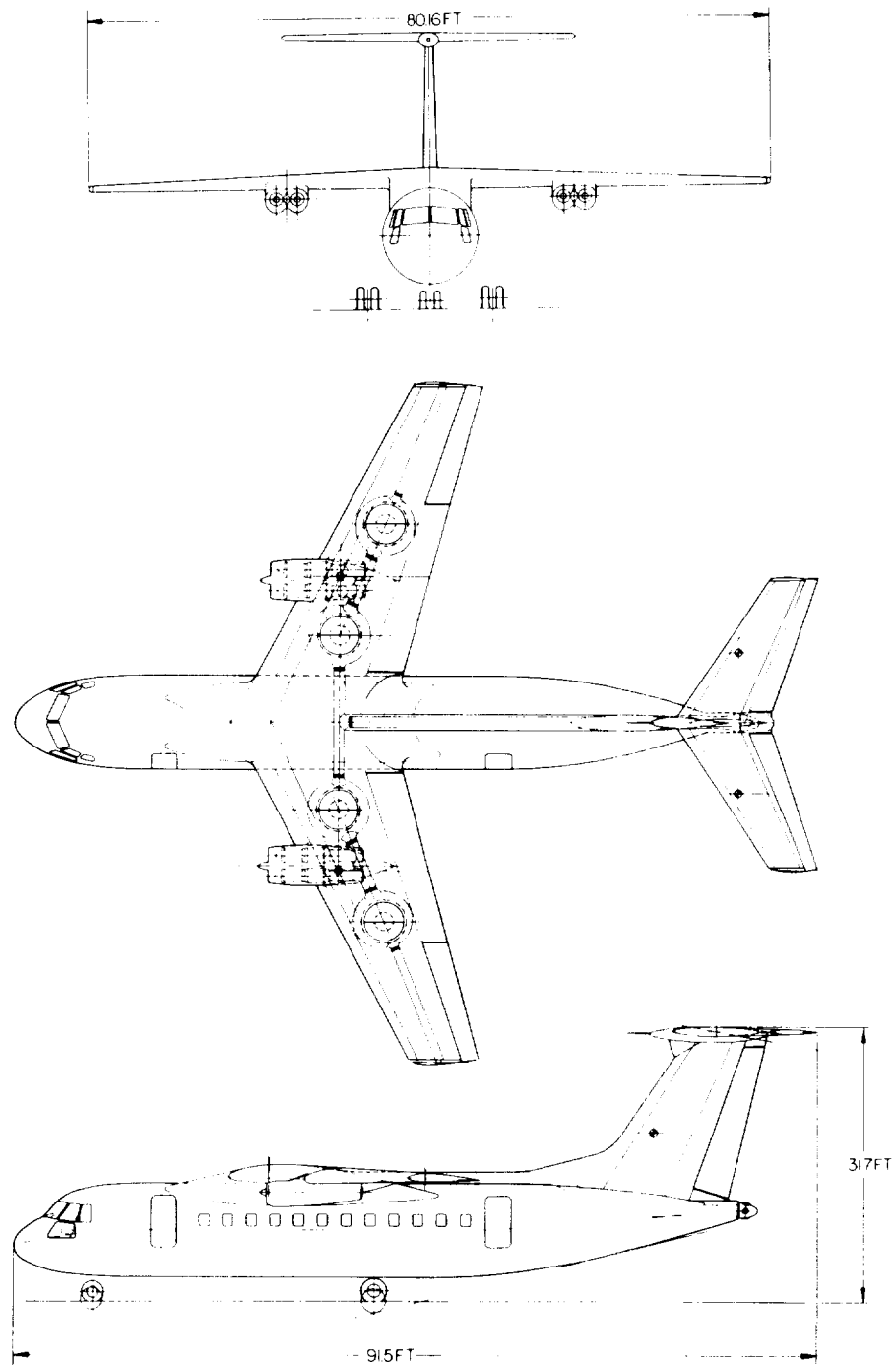


Figure 24

GENERAL ARRANGEMENT  
120 PASSENGER  
FAN-IN-WING STOL

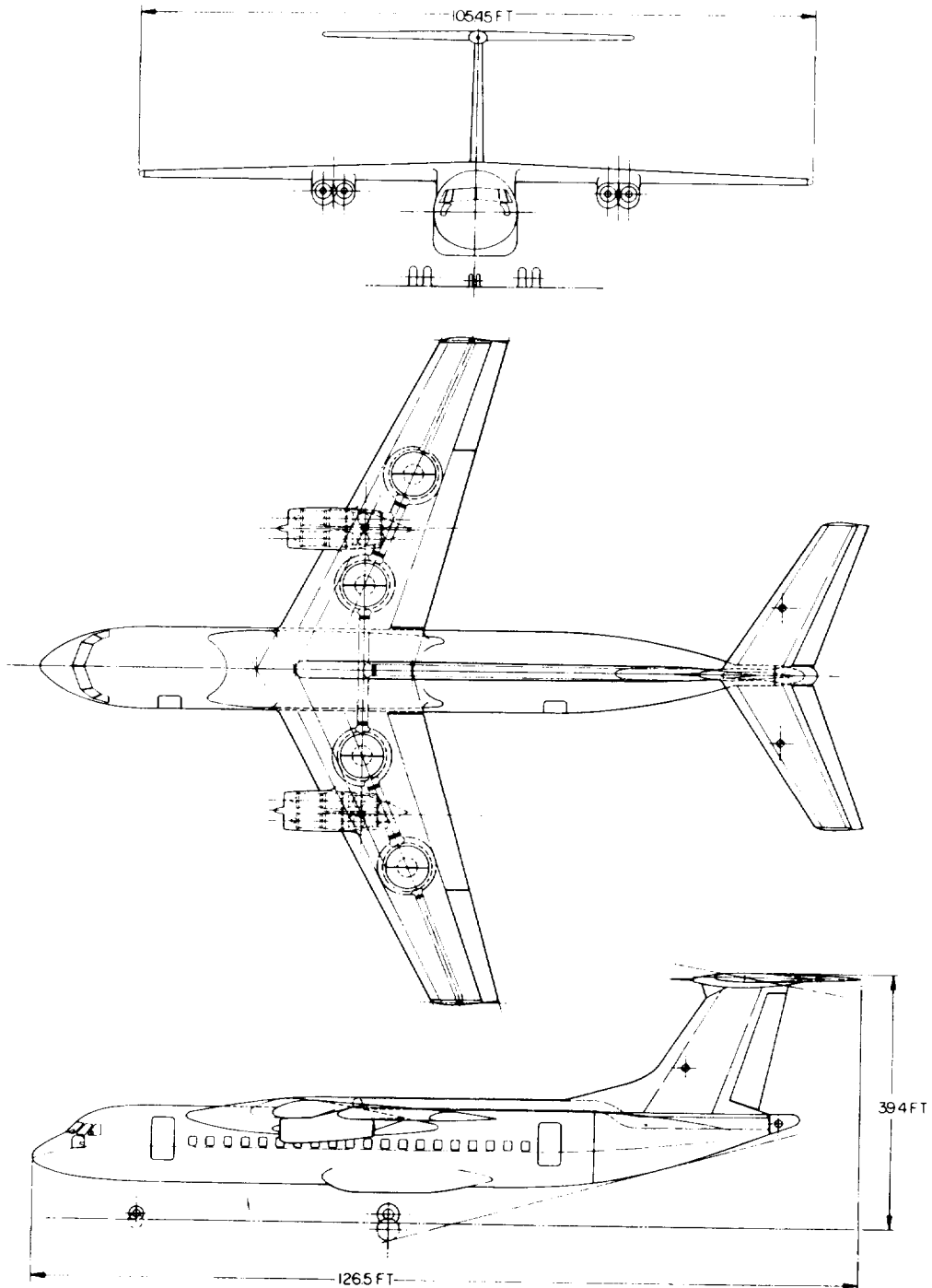


Figure 25  
PROPULSION SYSTEM SCHEMATIC - FAN-IN-WING STOL

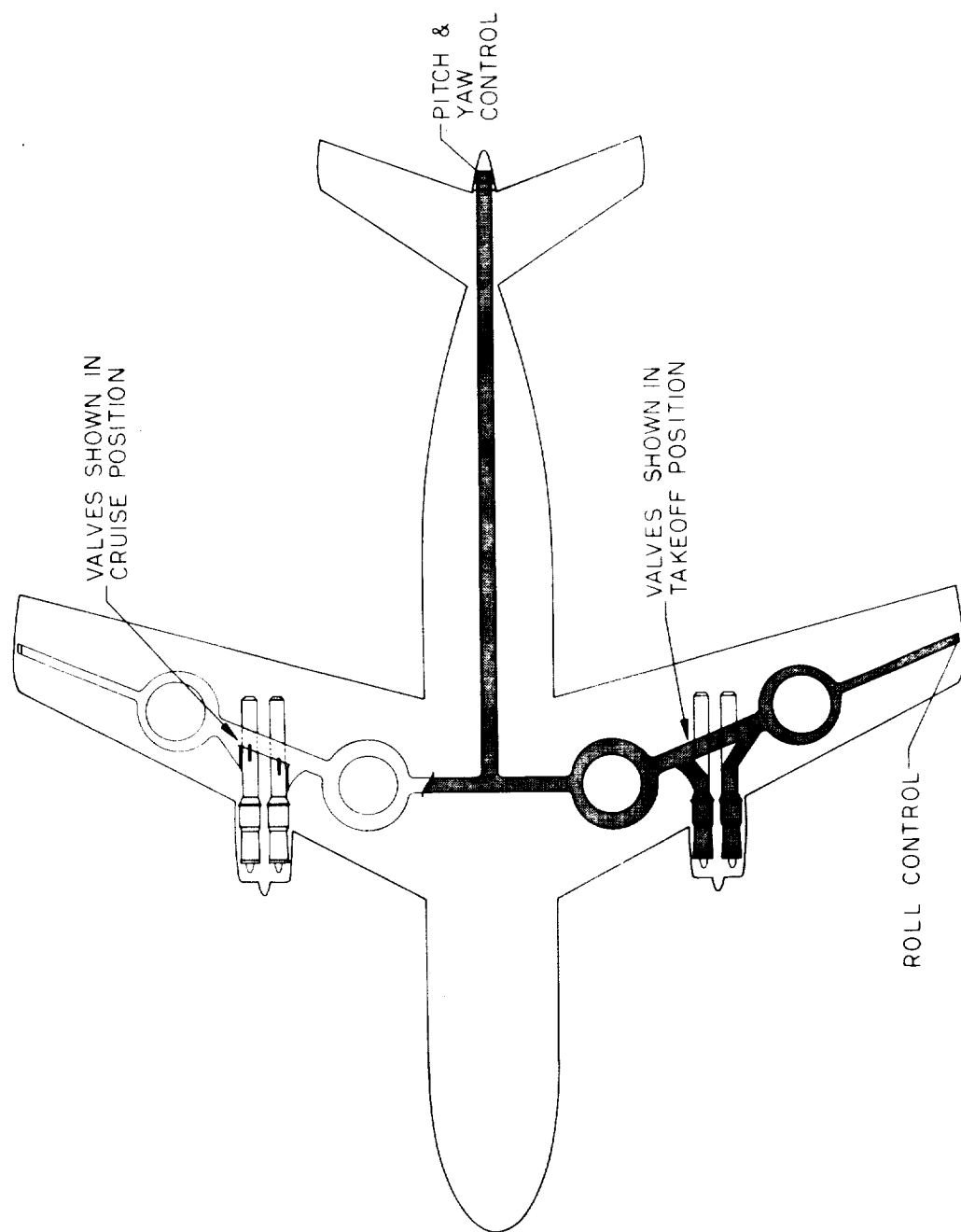


Figure 26

FAN-IN-WING - WEIGHT STATEMENTS - FINAL SELECTED DESIGNS  
(pounds)

	<u>60 Passenger</u>	<u>120 Passenger</u>
WING	6,695	13,500
EMPENNAGE	2,780	4,270
FUSELAGE	6,865	13,440
LANDING GEAR	2,580	4,880
SURFACE CONTROLS	1,515	1,925
HYDRAULICS	445	570
INSTRUMENTS	430	490
ELECTRICAL	950	1,800
ELECTRONICS	850	1,100
FURNISHINGS AND EQUIPMENT	5,060	9,355
AIR CONDITIONING AND ANTI-ICING	1,575	3,010
AUXILIARY POWER UNIT	370	420
NACELLES	1,620	2,620
PROPULSION	<u>7,890</u>	<u>13,315</u>
WEIGHT EMPTY	39,625	70,695
CREW	520	660
MISCELLANEOUS USEFUL LOAD	260	510
ENGINE OIL	105	190
UNUSABLE FUEL	<u>210</u>	<u>375</u>
OPERATING WEIGHT	40,720	72,430
PAYLOAD	<u>13,200</u>	<u>26,400</u>
ZERO FUEL WEIGHT	53,920	98,830
USABLE FUEL	<u>13,980</u>	<u>25,170</u>
- GROSS WEIGHT	67,900 pounds	124,000 pounds

Figure 27

FAN-IN-WING STOL (1000-FOOT)  
 COMBINED CONTROL POWER - PERCENTAGE OF SINGLE AXIS REQUIREMENT  
 C.G. at 25% MAC  
 Landing Mode, Trimmed with All Engines Operating, V = 50 Knots

60-Passenger				
Combined Control Available in	Control Condition			Aerodynamic Control
	Max. Pitch	Max. Yaw	Max. Roll	
Pitch - $\ddot{\theta}$	129	95.5	90	52.5
Yaw - $\ddot{\psi}$	52.5	100	52.5	52.5
Roll - $\ddot{\phi}$	50	50	100	15.5
100% Values: $\ddot{\theta} = 0.4 \text{ rads/sec}^2$ , $\ddot{\psi} = 0.2 \text{ rads/sec}^2$ , $\ddot{\phi} = 0.45 \text{ rads/sec}^2$				

120-Passenger				
Combined Control Available in	Control Condition			Aerodynamic Control
	Max. Pitch	Max. Yaw	Max. Roll	
Pitch - $\ddot{\theta}$	131	93	86	53
Yaw - $\ddot{\psi}$	50	100	50	41
Roll - $\ddot{\phi}$	50	50	100	15.5
100% Values: $\ddot{\theta} = 0.32 \text{ rads/sec}^2$ , $\ddot{\psi} = 0.16 \text{ rads/sec}^2$ , $\ddot{\phi} = 0.36 \text{ rads/sec}^2$				

Figure 28

FAN-IN-WING STOL (1000-FOOT) STABILITY SUMMARY  
 Landing Configuration at Maximum Gross Weight, V = 50 Knots

	Unit	60-Passenger	120-Passenger
Directional Stability	$1/\text{sec}^2$	0.44	0.37
Directional Damping	$1/\text{sec}$	-0.15	-0.13
Roll Damping	$1/\text{sec}$	-0.39	-0.388
Pitch Damping Ratio (C.G. at 31.5% MAC)		0.31	0.43
Dihedral Effect	$1/\text{sec}^2$	-1.20	-0.77

Figure 29

FIGURE OF MERIT VS ROTOR TIP SPEED

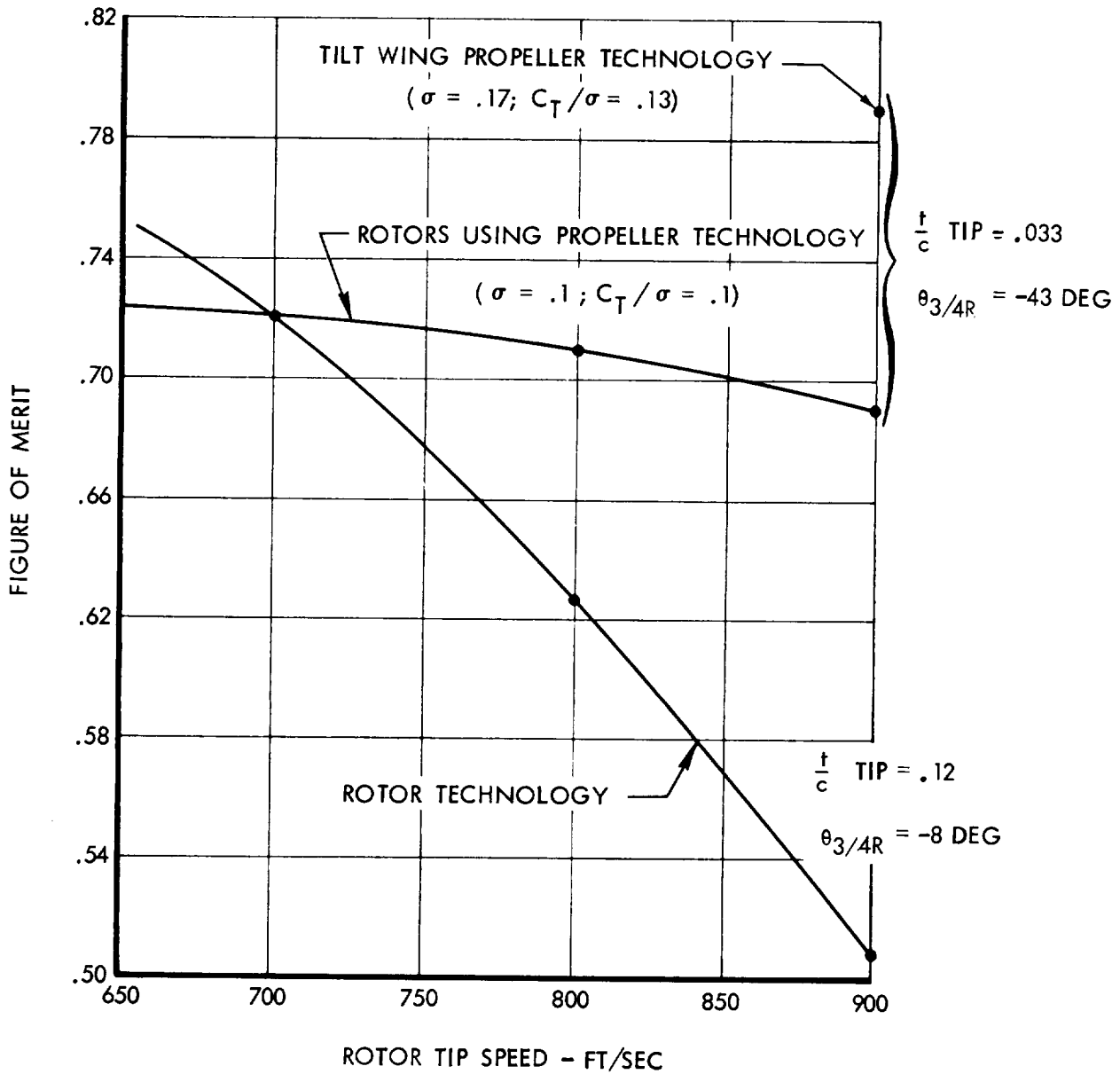


Figure 30

COMPARISON OF TILT ROTOR CHARACTERISTICS  
PROPELLER VS ROTOR TECHNOLOGY

	Prop Technology	Rotor Technology
Gross Weight (lb)	65,000	77,900
DOC (dollars/seat mile)	0.0267	0.0301
Block Speed (knots)	296	311
Cruise Velocity (knots)	363	392
Cruise Altitude (ft)	25,000	35,000
Rotor Tip Speed (ft/sec)	900	800
Prop Diameter (rotor) (ft)	56.4	66.0
Disk Loading (lb/ft <sup>2</sup> )	13	11.4
Solidity (main rotor)	0.086	0.095
Activity Factor	52.6	58.3
Figure of Merit (rotor)	0.69	0.621
Propulsive Efficiency (cruise)	0.765	0.765
RHP/Engine	3840	5580
Wing Loading (lb/ft <sup>2</sup> )	77.8	72
Wing Area (ft <sup>2</sup> )	835	1077
Wing Span (ft)	70.8	80.4
Aspect Ratio	6	6

Figure 31

GENERAL ARRANGEMENT  
60 PASSENGER  
TILT ROTOR - VTOL

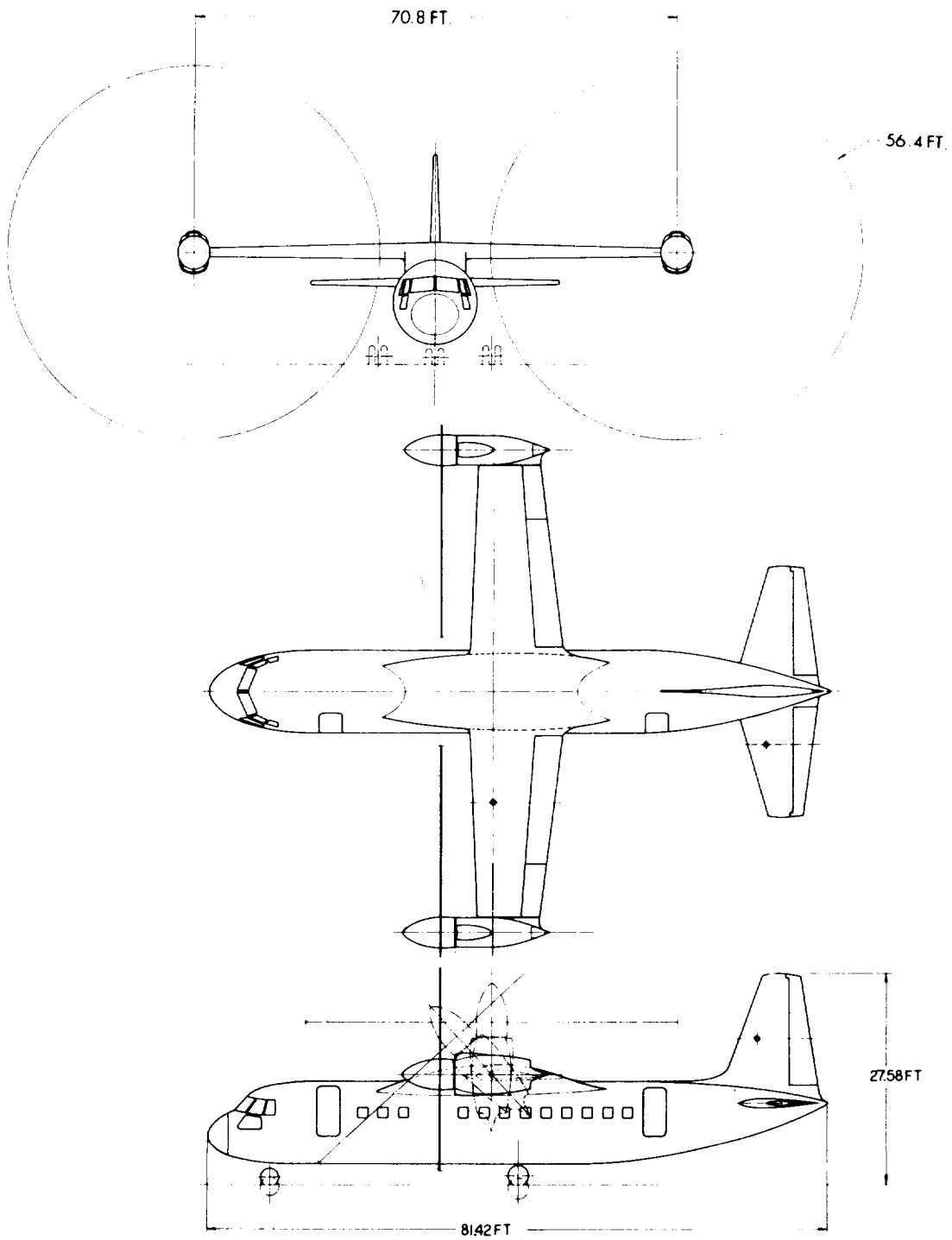


Figure 32

GENERAL ARRANGEMENT  
120 PASSENGER  
TILT ROTOR - VTOL

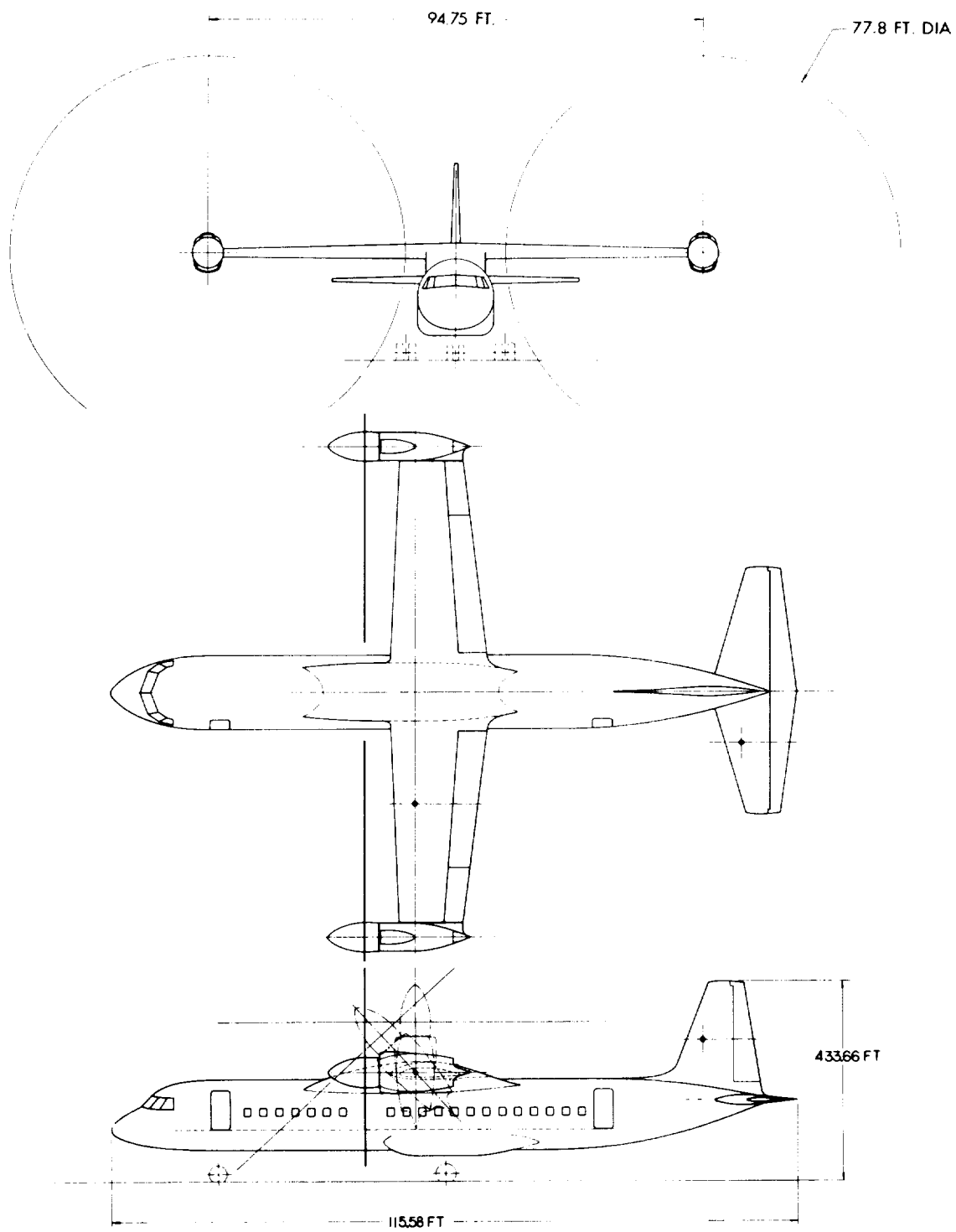


Figure 33

PROPULSION SYSTEM SCHEMATIC - TILT ROTOR VTOL

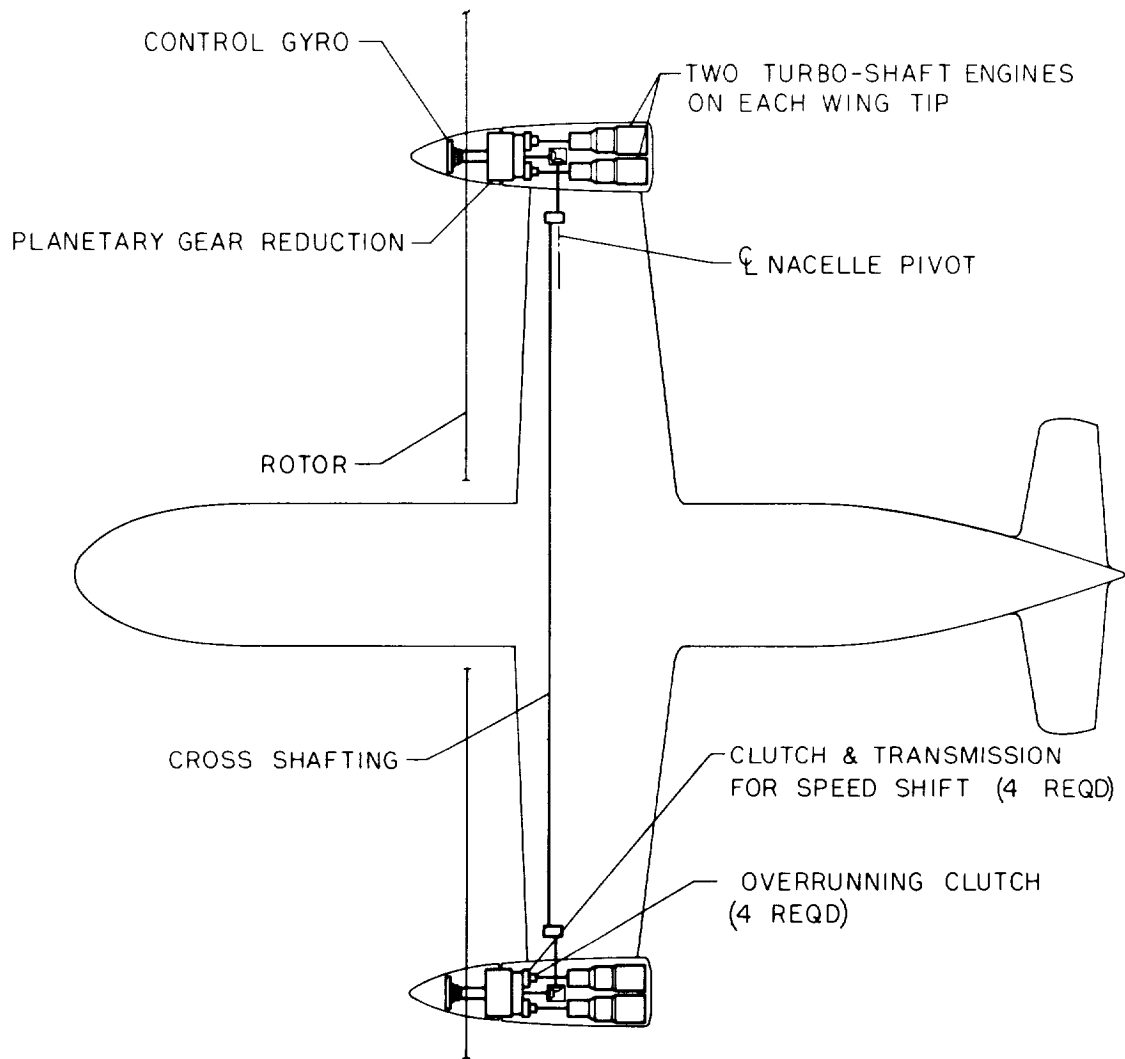


Figure 34

## TILT ROTOR - WEIGHT STATEMENTS - FINAL SELECTED DESIGNS

(pounds)

	<u>60 Passenger</u>	<u>120 Passenger</u>
WING	4,755	11,080
EMPENNAGE	1,275	2,680
FUSELAGE	6,320	12,750
LANDING GEAR	2,390	4,870
SURFACE CONTROLS	2,580	3,510
HYDRAULICS	405	540
INSTRUMENTS	410	470
ELECTRICAL	950	1,800
ELECTRONICS	850	1,100
FURNISHINGS AND EQUIPMENT	5,040	9,330
AIR CONDITIONING AND ANTI-ICING	1,660	3,020
AUXILIARY POWER UNIT	365	420
NACELLES	2,600	4,255
PROPULSION	14,735	27,950
WEIGHT EMPTY	<u>44,335</u>	<u>83,775</u>
CREW	520	660
MISCELLANEOUS USEFUL LOAD	260	510
ENGINE OIL	185	340
UNUSABLE FUEL	100	175
OPERATING WEIGHT	<u>45,400</u>	<u>85,460</u>
PAYLOAD	13,200	26,400
ZERO FUEL WEIGHT	<u>58,600</u>	<u>111,860</u>
USABLE FUEL	6,400	11,640
GROSS WEIGHT	<u>65,000 pounds</u>	<u>123,500 pounds</u>

Figure 35  
GENERAL ARRANGEMENT  
60 PASSENGER  
LIFT/CRUISE FAN

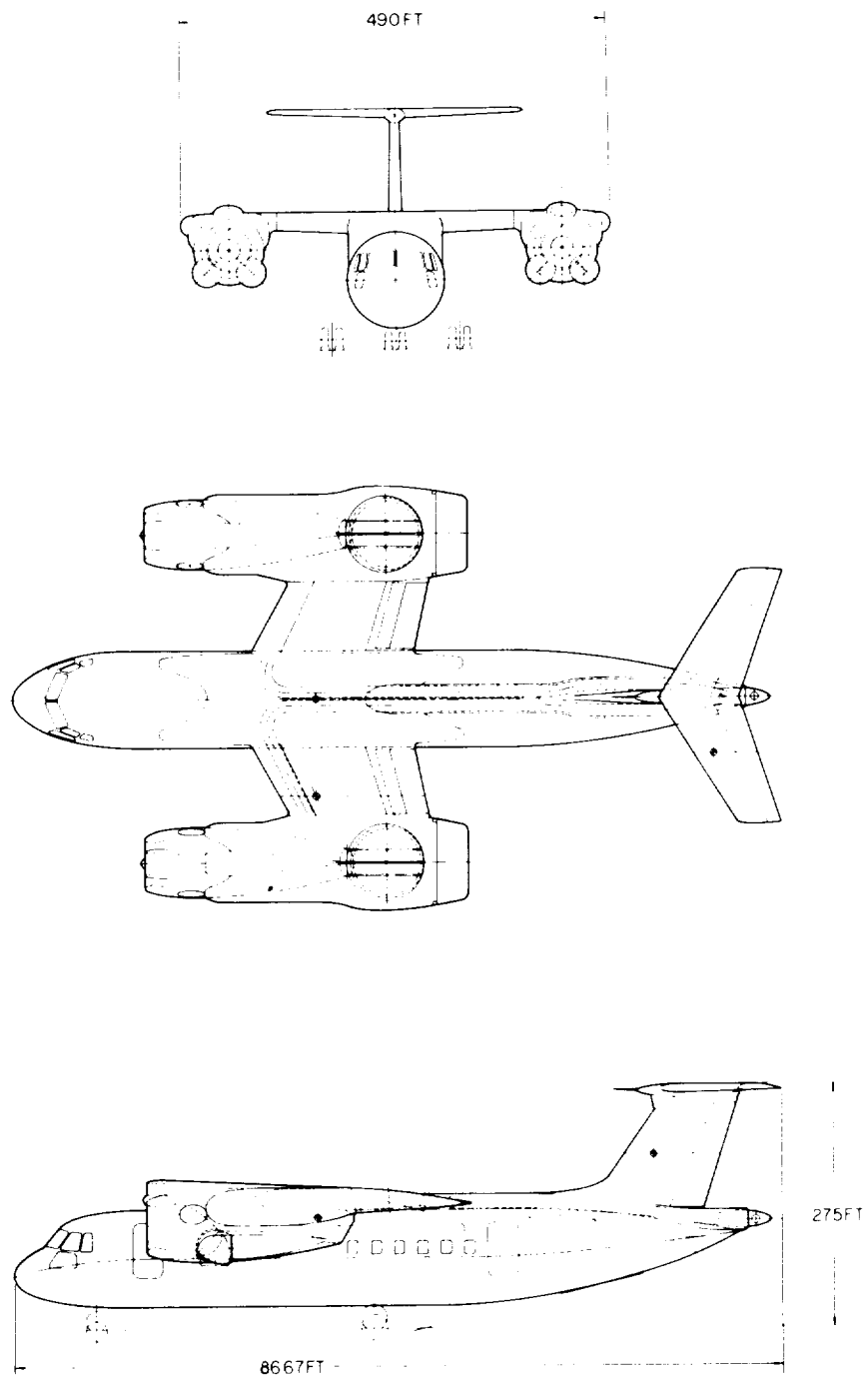


Figure 36  
GENERAL ARRANGEMENT  
120 PASSENGER  
LIFT/CRUISE FAN

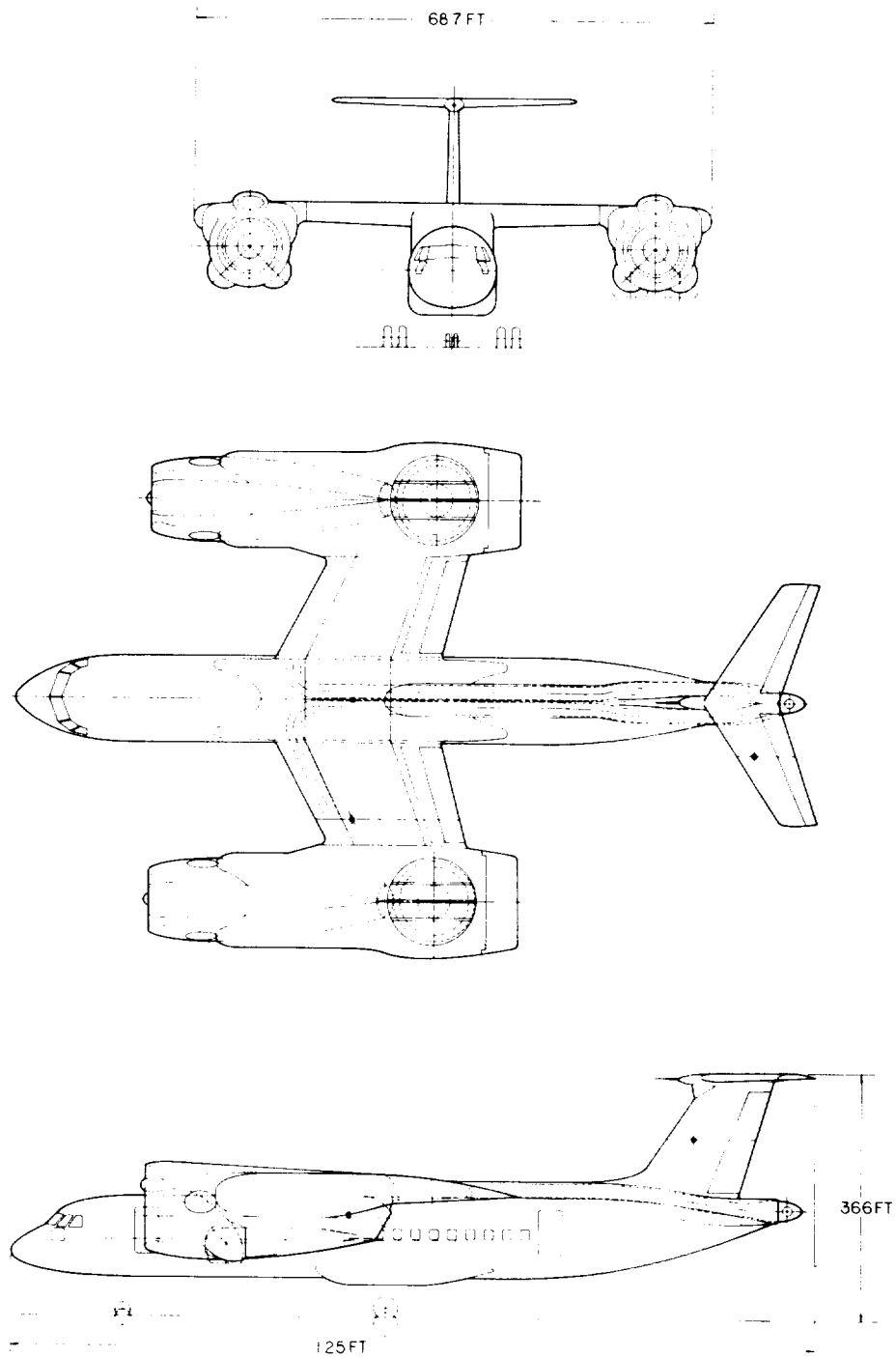


Figure 37

# PROPULSION SYSTEM SCHEMATIC - LIFT/CRUISE FAN

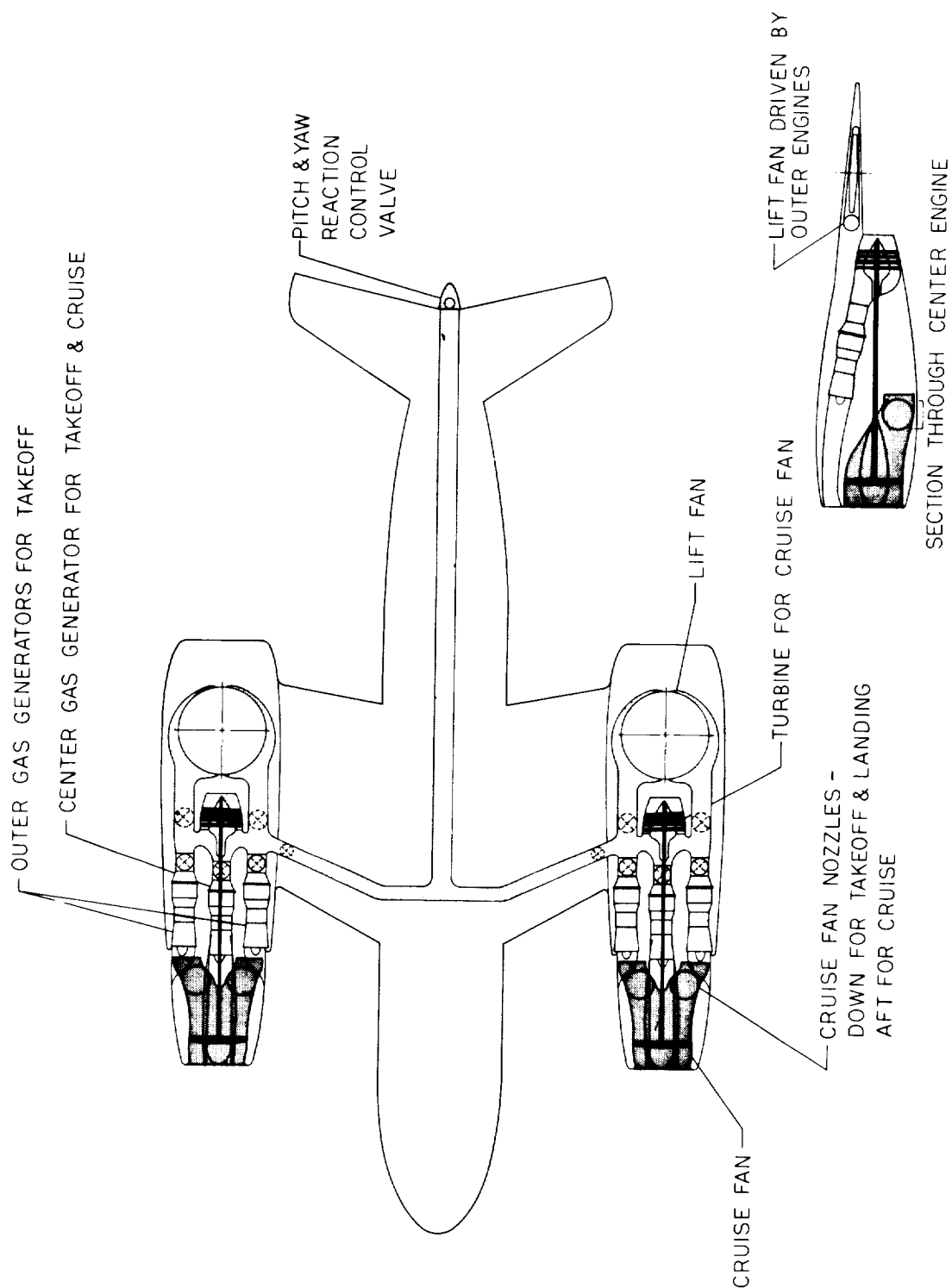


Figure 38

LIFT/CRUISE FAN - WEIGHT STATEMENTS - FINAL SELECTED DESIGN  
(pounds)

	<u>60 Passenger</u>	<u>120 Passenger</u>
WING	4,290	10,115
EMPENNAGE	1,600	1,870
FUSELAGE	6,970	14,000
LANDING GEAR	2,740	5,665
SURFACE CONTROLS	1,695	2,555
HYDRAULICS	325	445
INSTRUMENTS	550	610
ELECTRICAL	950	1,800
ELECTRONICS	850	1,100
FURNISHINGS AND EQUIPMENT	5,070	9,425
AIR CONDITIONING AND ANTI-ICING	1,570	3,010
AUXILIARY POWER UNIT	375	445
NACELLES	4,940	10,740
PROPULSION	14,000	28,615
WEIGHT EMPTY	<u>45,925</u>	<u>90,395</u>
CREW	520	660
MISCELLANEOUS USEFUL LOAD	260	510
ENGINE OIL	175	390
UNUSABLE FUEL	175	345
OPERATING WEIGHT	<u>47,055</u>	<u>92,300</u>
PAYLOAD	13,200	26,400
ZERO FUEL WEIGHT	<u>60,255</u>	<u>118,700</u>
USABLE FUEL	11,545	22,900
GROSS WEIGHT	<u>71,800 pounds</u>	<u>141,600 pounds</u>

Figure 39

LIFT/CRUISE FAN AIRPLANE  
60 PASSENGER

DISTANCE TRAVELED DURING TRANSITION MANEUVER  
HORIZONTAL FLIGHT PATH  
 $C_L \approx 0.10$

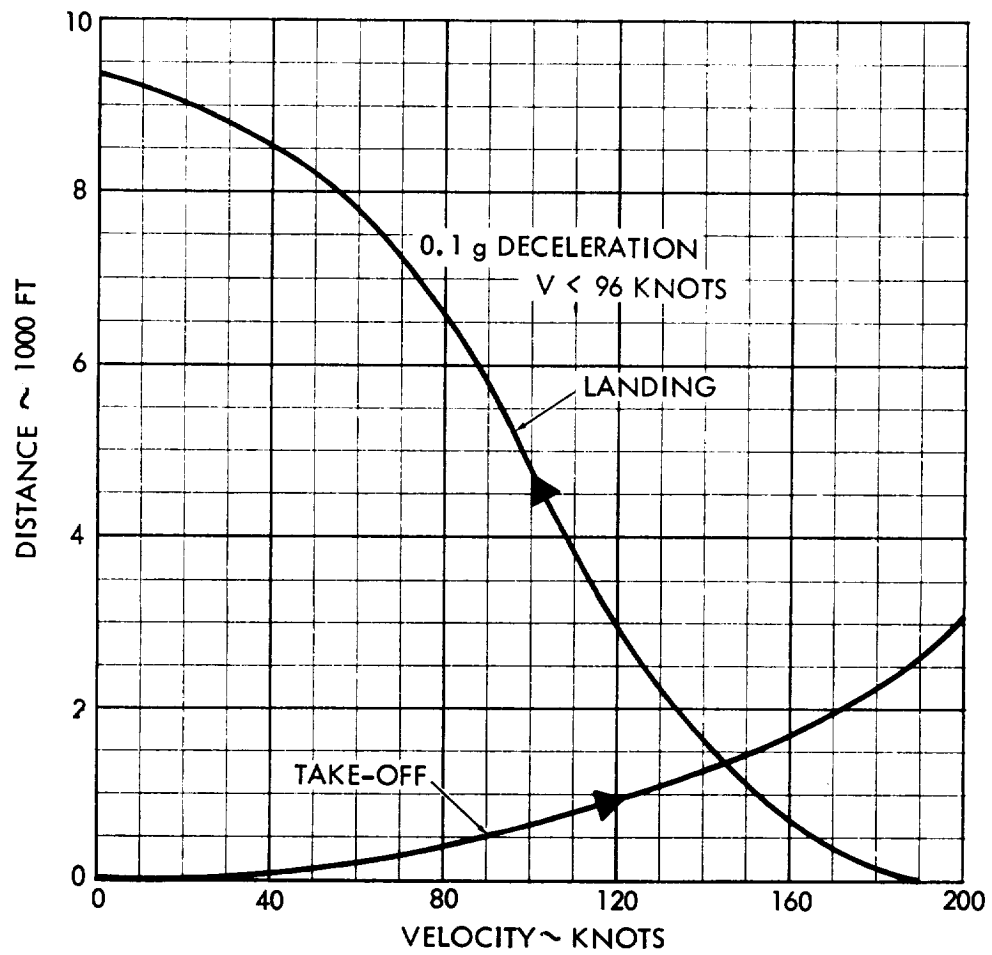


Figure 40  
LIFT/CRUISE FAN AIRPLANE  
60 PASSENGER  
LAPSED TIME VERSUS TRANSITION FLIGHT SPEED  
HORIZONTAL FLIGHT PATH  
 $C_L \approx 0.10$

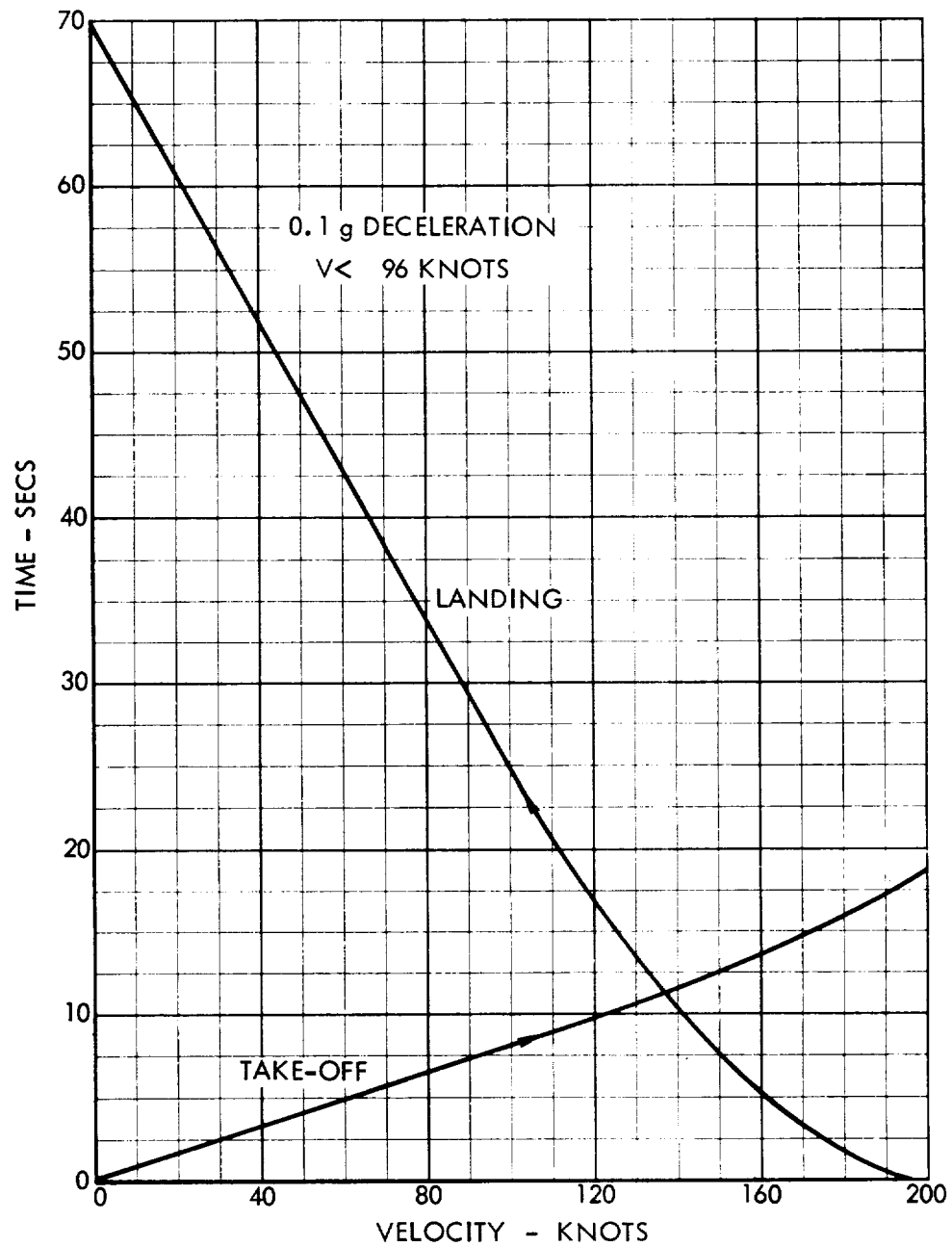


Figure 41

## COMPARISON OF FOUR OPTIMIZED STOPPED ROTOR CONFIGURATIONS

Parameter	Single Rotor		Twin Rotor	
	Prop Driven	Jet Driven	Prop Driven	Jet Driven
Gross Weight (lb)	78,200	76,600	87,700	84,500
Wing Area (ft <sup>2</sup> )	656	696	643	867
Wing Span (ft)	62.8	64.6	67.0	72.1
Aspect Ratio	6	6	7	6
Cruise Velocity (knots)	402	438	399	435
Cruise Altitude (ft)	20,400	35,000	25,500	35,000
RHP/Engine	4290	4150	6886	5982
Prop Activity Factor	160	----	200	----
Prop Diameter (ft)	16	----	18	----
Prop Tip Speed (ft/sec)	800	----	700	----
Rotor Diameter (ft)	119.2	118.1	65.1	70.1
Solidity of Main Rotor	0.0598	0.0598	0.1138	0.0934
Disk Loading (lbs/ft <sup>2</sup> )	7	7	12.6	11
Tail Rotor Radius (ft)	9.56	9.48	----	----
Rotor Tip Speed (ft/sec)	800	800	800	800
Figure of Merit	0.621	0.621	0.621	0.621
DOC (dollars/seat mile)	.0288	0.0312	0.0392	0.034

Figure 42

COMPARISON OF STOWED ROTOR CHARACTERISTICS  
PROPELLER VS ROTOR TECHNOLOGY

	Prop Technology	Rotor Technology
Gross Weight (lb)	71,000	78,200
DOC (dollars/seat mile)	0.0265	0.0288
Block Speed (knots)	312	313
Cruise Velocity (knots)	400	402
Cruise Altitude (ft)	20,000	20,400
Rotor Tip Speed (ft/sec)	900	800
Main Rotor Diameter (ft)	83.4	119.2
Disk Loading (lb/ft <sup>2</sup> )	13	7
Solidity of Main Rotor	0.0878	0.0598
Rotor Figure of Merit	0.69	0.621
Prop Diameter (ft)	16	16
Activity Factor (props)	140	140
Propulsive EFF (cruise)	0.85	0.85
RHP/Engine	4350	4290
Wing Loading (lb/ft <sup>2</sup> )	120	120
Wing Area (ft <sup>2</sup> )	592	656
Wing Span (ft)	60	62.8
Aspect Ratio	6	6

Figure 43  
60 PASSENGER STOPPED ROTOR VTOL  
GENERAL ARRANGEMENT

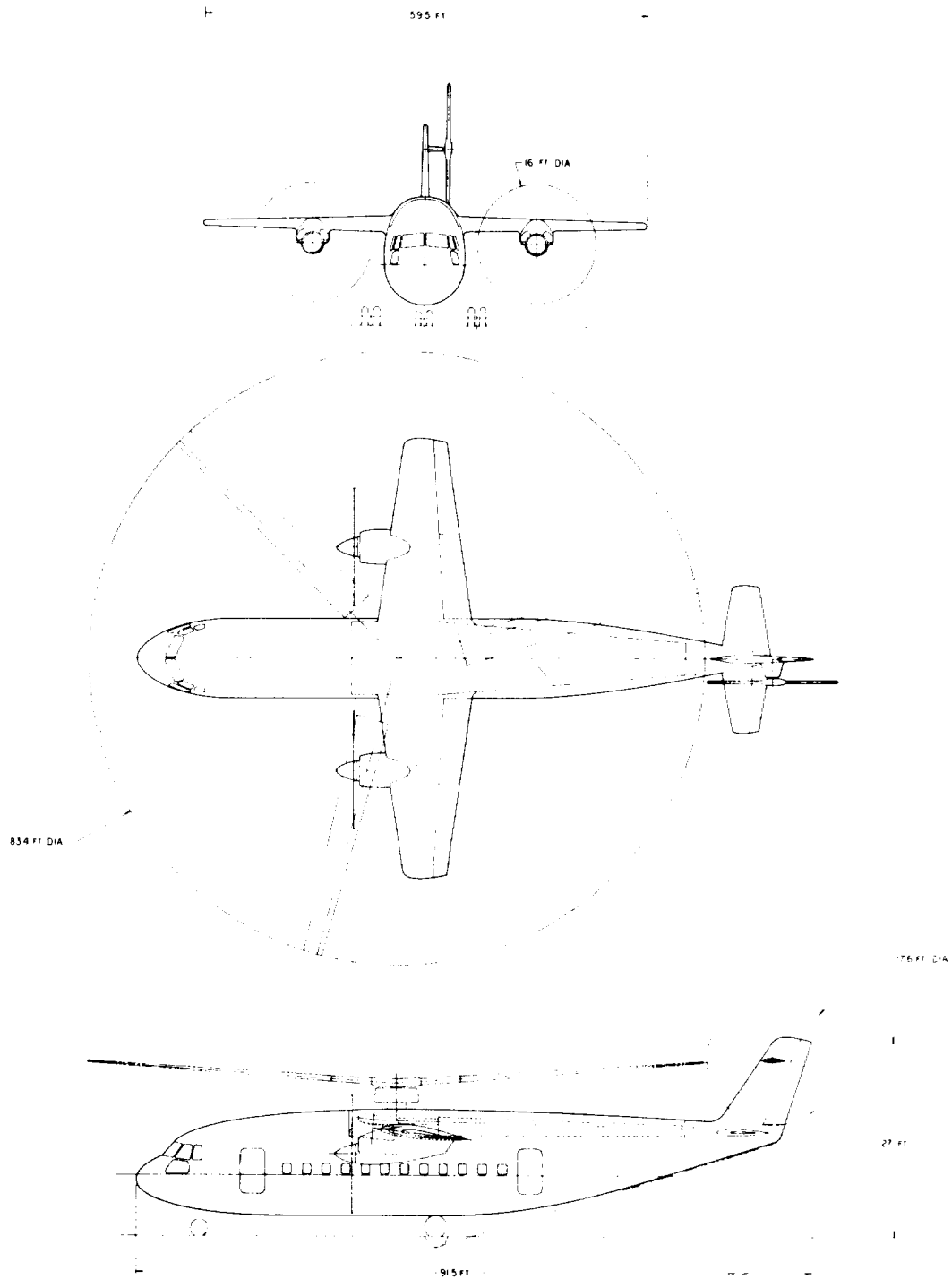


Figure 44

PROPULSION SYSTEM SCHEMATIC - STOPPED ROTOR VTOL

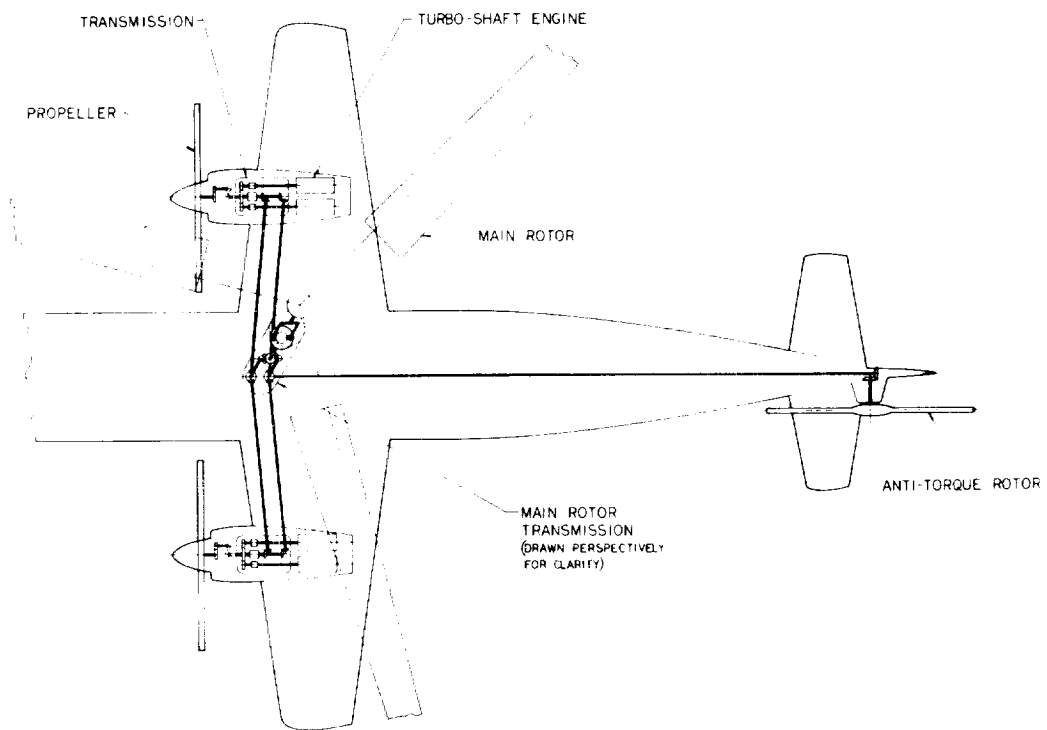


Figure 45

STOPPED ROTOR VTOL - WEIGHT STATEMENT - FINAL POINT DESIGN

	(pounds)
WING	3,600
EMPENNAGE	610
FUSELAGE	7,010
LANDING GEAR	2,720
FLIGHT CONTROLS	2,440
HYDRAULICS	360
INSTRUMENTS	405
ELECTRICAL	950
ELECTRONICS	850
FURNISHINGS & EQUIPMENT	5,060
AIR CONDITIONING & ANTI-ICING	1,600
AUXILIARY POWER UNIT	370
NACELLES	2,880
PROPULSION	<u>19,895</u>
WEIGHT EMPTY	48,750
CREW	520
MISCELLANEOUS USEFUL LOAD	260
ENGINE OIL	210
UNUSABLE FUEL	<u>120</u>
OPERATING WEIGHT	49,860
PAYLOAD	<u>13,200</u>
ZERO FUEL WEIGHT	63,060
USABLE FUEL	<u>7,940</u>
GROSS WEIGHT	71,000 pounds

Figure 46

DIRECT OPERATING COST - 60 PASSENGER AIRCRAFT  
 500-mile Stage Length - Production Quantity of 300  
 2000-hour Utilization - 10.25 minutes Fixed Time

	<u>Gross Weight (lb)</u>	<u>Block Speed (mi/hr)</u>	<u>D.O.C. cents per ASM</u>
<u>Parametric Aircraft</u>			
Tilt Rotor (VTOL)	58,200	361	2.27
Lift/Cruise Fan (VTOL)	70,000	410	2.82
Deflected Slipstream (2000-ft STOL)	45,600	281	1.92
Jet Flap (2000-ft STOL)	59,500	425	2.18
Fan-In-Wing (1000-ft STOL)	63,700	441	2.54
<u>Final Aircraft</u>			
Stopped Rotor (VTOL)	71,000	359	2.65
Tilt Rotor (VTOL)	65,000	340	2.67
Lift/Cruise Fan (VTOL)	71,800	409	2.87
Deflected Slipstream (2000-ft STOL)	46,900	281	1.96
Jet Flap (2000-ft STOL)	63,200	424	2.26
Fan-In-Wing (1000-ft STOL)	67,900	440	2.67

Figure 47

DIRECT OPERATING COSTS AT VARIOUS STAGE LENGTHS  
2000 HOURS UTILIZATION - 10.25 MIN. FIXED TIME

A - 300 Production Units including RDT&E

B - 600 Production Units excluding RDT&E

Vehicle	No. Pass.		Stage Length - statute miles				
			25	50	100	200	500
Tilt Rotor VTOL	60	A	9.42	5.71	3.76	2.79	2.27
		B	8.08	4.88	3.20	2.35	1.88
	120	A	7.11	4.28	2.81	2.07	1.65
Lift/Cruise Fan VTOL	60	A	13.82	8.08	5.16	3.64	2.82
		B	12.14	7.07	4.49	3.15	2.37
	120	A	11.93	6.95	4.41	3.11	2.37
Deflected Slipstream STOL	60	A	6.84	4.29	2.96	2.30	1.92
		B	5.72	3.56	2.42	1.87	1.53
	120	A	5.15	3.26	2.25	1.76	1.47
Jet Flap STOL, 2000 ft	60	A	10.56	6.32	4.06	2.92	2.18
		B	9.17	5.48	3.51	2.49	1.81
	120	A	8.57	5.22	3.41	2.47	1.71
Fan In Wing STOL, 1000 ft	60	A	12.42	7.42	4.84	3.44	2.54
		B	10.87	6.48	4.22	2.79	2.15
	120	A	9.60	5.76	3.73	2.67	1.96

Note: Aircraft are final parametric designs and not final point designs.

Figure 48

DIRECT OPERATING COST BY MAJOR CATEGORY  
60 Passenger Aircraft\*  
Cents Per Available Seat Mile

Cost Category	Stopped Rotor	Tilt Rotor	Lift/Cruise Fan	Deflected Slipstream	Jet Flap	Fan-In-Wing
<u>Parametric A/C</u>						
Crew	—	0.31¢ 14%	0.29¢ 10%	0.35¢ 18%	0.29¢ 13%	0.28¢ 11%
Fuel	—	0.20 9%	0.45 16%	0.15 8%	0.42 19%	0.59 23%
Insurance	—	0.33 14%	0.43 15%	0.32 17%	0.29 13%	0.33 13%
Depreciation	—	0.88 39%	1.27 45%	0.81 42%	0.77 36%	0.93 37%
Maintenance	—	0.55 24%	0.38 14%	0.29 15%	0.41 19%	0.41 16%
TOTAL		2.27¢ 100%	2.82¢ 100%	1.92¢ 100%	2.18¢ 100%	2.54¢ 100%
<u>Final A/C</u>						
Crew	0.31¢ 12%	0.32¢ 12%	0.29¢ 10%	0.35¢ 18%	0.29¢ 13%	0.28¢ 11%
Fuel	0.37 14%	0.26 10%	0.46 16%	0.15 8%	0.43 19%	0.62 23%
Insurance	0.38 14%	0.38 14%	0.43 15%	0.33 17%	0.30 13%	0.36 13%
Depreciation	1.07 40%	1.11 41%	1.30 45%	0.83 42%	0.81 36%	0.98 37%
Maintenance	0.52 20%	0.60 23%	0.39 14%	0.30 15%	0.43 19%	0.43 16%
TOTAL	2.65¢ 100%	2.67¢ 100%	2.87¢ 100%	1.96¢ 100%	2.26¢ 100%	2.67¢ 100%

\*500 mile stage length - production quantity of 300 - 2000 hours  
Utilization: 10.25 minutes fixed time.

Figure 49

## TOTAL AIRCRAFT COSTS (millions)

## 60-PASSENGER AIRCRAFT - FINAL DESIGNS

<u>Component</u>	<u>Stopped Rotor</u>	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>	<u>Deflected Slipstream</u>	<u>Jet Flap</u>	<u>Fan-in-Wing</u>
Airframe	\$2.314	\$2.352	\$2.856	\$1.787	\$2.337	\$2.762
Engines	0.287	0.253	0.739	0.084	0.525	0.485
Propellers	0.036	-	-	0.055	-	-
Rotor	0.178	0.144	-	-	-	-
Gearbox	0.218	0.158	-	0.033	-	-
Electronics	0.127	0.127	0.127	0.127	0.127	0.127
Fans	-	-	0.537	-	-	0.281
Sub-Total	\$3.160	\$3.034	\$4.259	\$2.086	\$2.989	\$3.655
RDT&E	0.977	0.897	0.988	0.654	0.873	0.951
TOTAL	\$4.137	3.931	5.247	2.740	3.862	\$4.606

## 120-PASSENGER AIRCRAFT - PARAMETRIC DESIGN

<u>Component</u>	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>	<u>Deflected Slipstream</u>	<u>Jet Flap</u>	<u>Fan-in-Wing</u>
Airframe	\$3.461	\$4.751	\$2.845	\$3.706	\$4.173
Engines	0.344	1.244	0.144	0.772	0.690
Propellers	-	-	0.093	-	-
Rotor	0.223	-	-	-	-
Gearbox	0.255	-	0.061	-	-
Electronics	0.165	0.165	0.165	0.165	0.165
Fans	-	0.962	-	-	0.425
Sub-Total	\$4.448	\$7.122	\$3.308	\$4.643	\$5.453
RDT&E	1.459	1.912	1.183	1.550	1.590
TOTAL	\$5.907	\$9.034	\$4.491	\$6.193	\$7.043

Figure 50

DIRECT OPERATING COST VS AIRCRAFT SIZE (NUMBER OF SEATS)

500 Mile Stage Length - 2000 Hours Utilization

Production Quantity 300 Aircraft Including RDT&E

10.25 Minutes Fixed Time

	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>	<u>Deflected Slipstream</u>	<u>Jet Flap</u>	<u>Fan-In-Wing</u>
<u>60 Seat Aircraft</u>					
Gross Weight (lbs)	58,200	70,000	45,600	59,500	63,700
Block Speed (mi/hr)	361	410	281	425	441
D.O.C. -¢/ASM	2.27	2.82	1.92	2.18	2.54
<u>120 Seat Aircraft</u>					
Gross Weight (lbs)	107,400	142,000	86,500	114,300	117,400
Block Speed	360	409	279	425	444
D.O.C. -¢/ASM	1.65	2.37	1.47	1.71	1.96
Percent Change					
Gross Weight	+84.5%	+107.1%	+89.7%	+92.1%	+84.3%
Block Speed	No Substantial Change				
D.O.C.	-27.3%	-16.0%	-23.4%	-21.6%	-22.8%

---

Note: Aircraft are final parametric designs and not final point designs.

Figure 51  
DIRECT OPERATING COSTS AT VARIOUS STAGE LENGTHS  
VS ANNUAL HOURS OF UTILIZATION  
TYPICAL 60-SEAT VEHICLE, 300 PRODUCTION UNITS  
10.25 MINUTES FIXED TIME

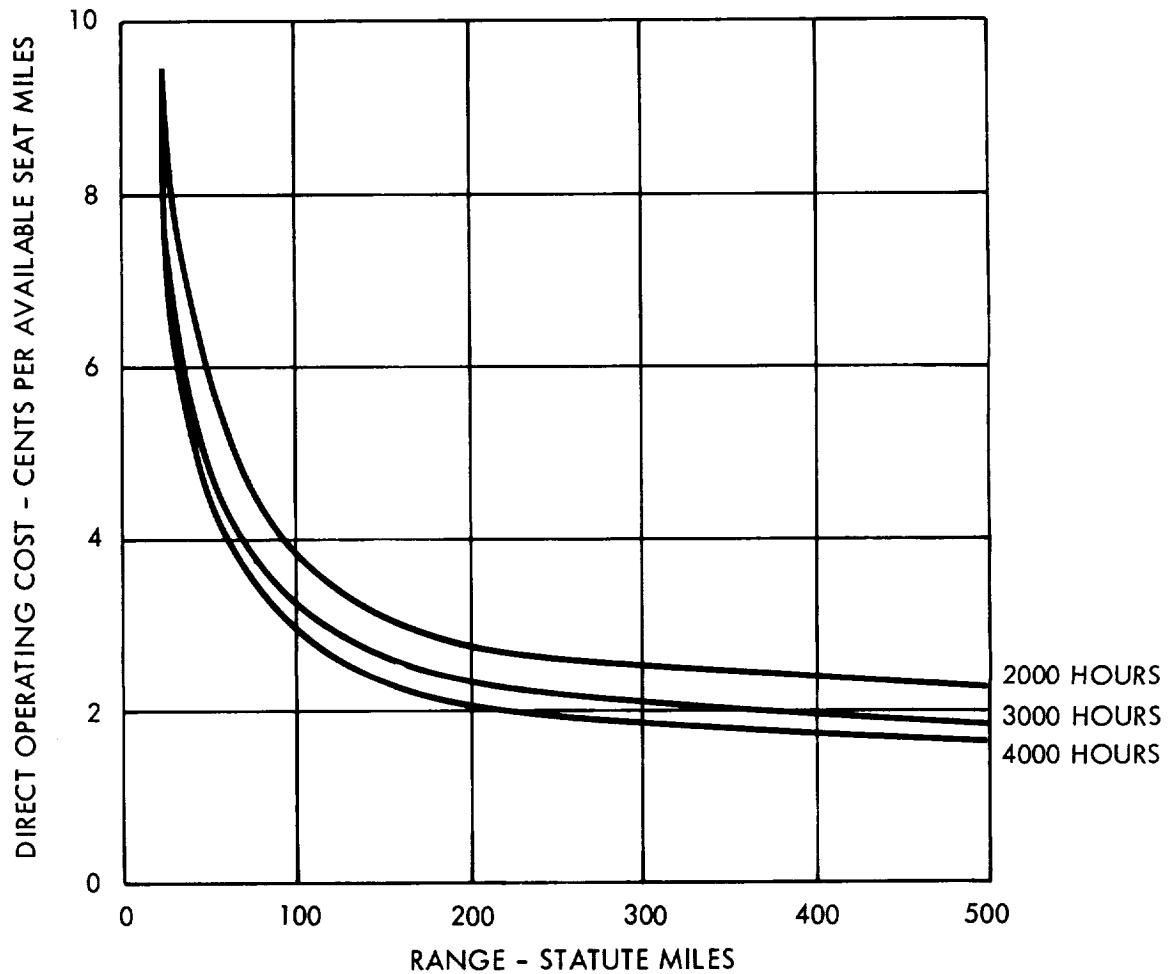


Figure 52

DIRECT OPERATING COSTS AT VARIOUS STAGE LENGTHS  
VS VARIATIONS IN FIXED TIME  
300 PRODUCTION UNITS - 2000 HOURS UTILIZATION - 60 SEATS

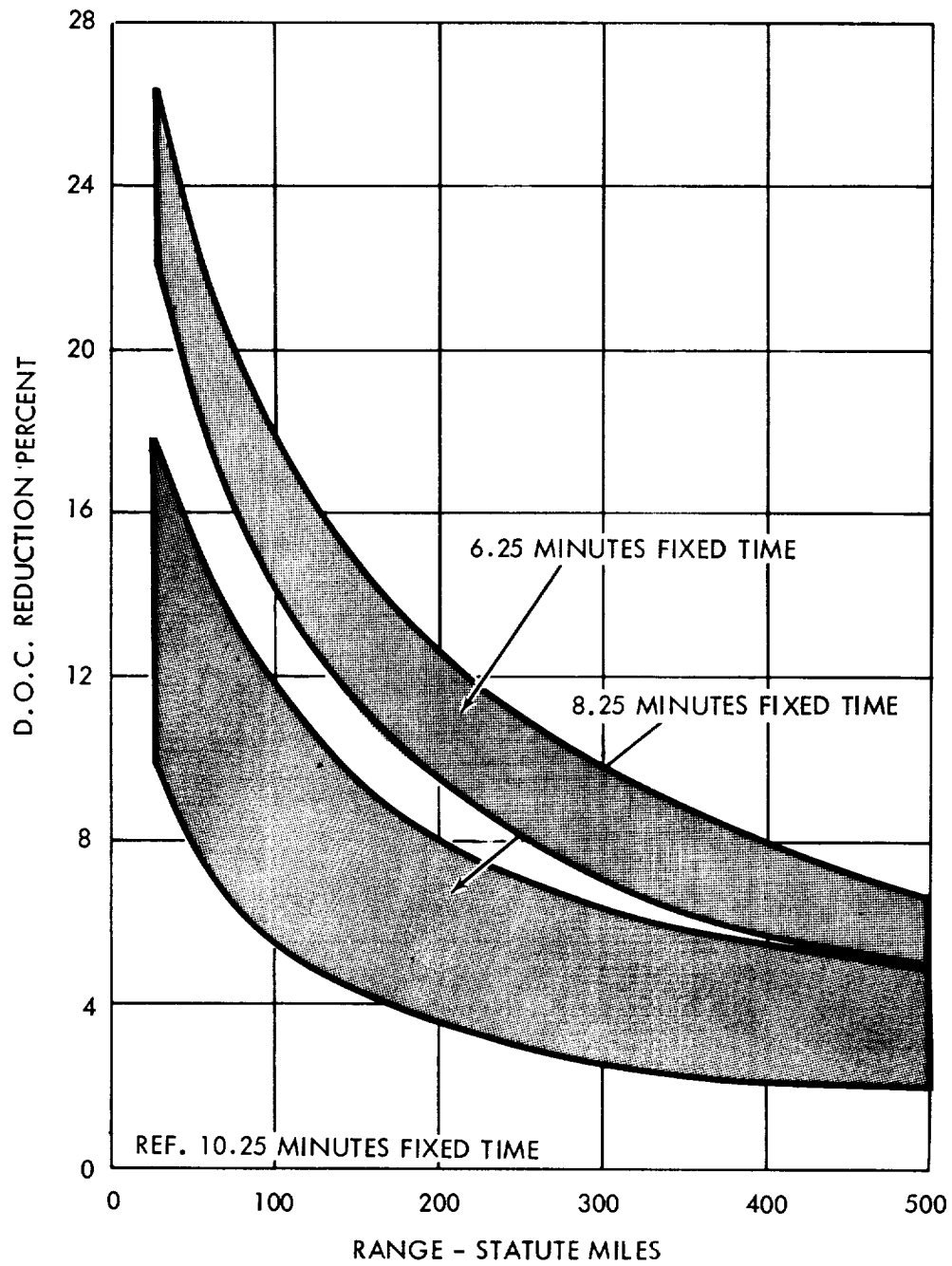


Figure 53

DIRECT OPERATING COST VS VARIATIONS IN ENGINE COST

60 Passenger Aircraft

500 Mile Stage Length - 300 Production Quantity

2000 Hours Utilization - 10.25 Minutes Fixed Time

<u>Engine Cost</u>	<u>Tilt Rotor</u>	<u>Lift/Cruise Fan</u>	<u>Deflected Slipstream</u>	<u>Jet Flap</u>	<u>Fan-in-Wing</u>
Estimate	2.27¢	2.82¢	1.92¢	2.18¢	2.54¢
50% of Estimate	2.20¢	2.50¢	1.88¢	2.01¢	2.30¢
% Change D.O.C.	-3.1%	-11.3%	-2.1%	-7.8%	-9.4%
200% of Estimate	-2.40¢	3.44¢	2.00¢	2.49¢	2.95¢
% Change D.O.C.	+5.7%	+22.0%	+4.2%	+14.2%	+16.2%

Note: Aircraft are final parametric designs and not final point designs.

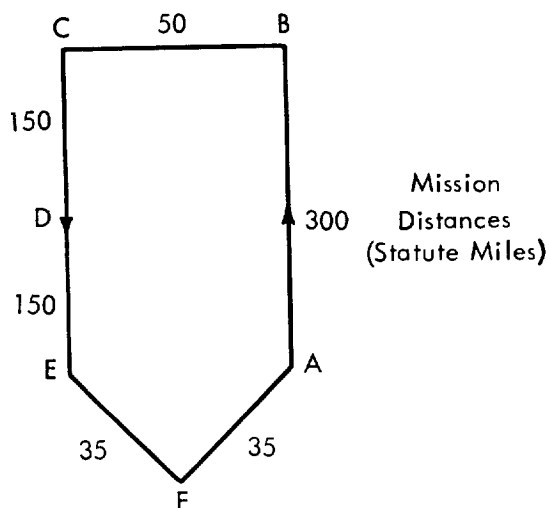
Figure 54

## DIRECT OPERATING COSTS - HYPOTHETICAL MISSION

Production Quantity 300 - 2000 Hours Utilization

Cents per available seat mile

	60 Seat Aircraft		120 Seat Aircraft	
	Hypothetical Mission	500 Mile Stage Length	Hypothetical Mission	500 Mile Stage Length
Tilt Rotor	2.58	2.27	1.95	1.65
Lift/Cruise Fan	3.51	2.82	3.21	2.37
Deflected Slipstream	2.24	1.92	1.73	1.47
Jet Flap	2.92	2.18	2.38	1.71
Fan-in-Wing	3.85	2.54	3.08	1.96



## Assumption

A, E, F are in one metropolitan area

B, C are in another

D, a smaller city

Fuel Available at A, C, E

Fuel Reserve for 1/2 hour loiter

Fixed Times (Corridor Concept)

STOL - 4 Min at each airport

(1 Min Landing &amp; Takeoff

2 Min Taxi)

VTOL - 2 Min at each airport

(1 Min Landing &amp; Takeoff)

Air Maneuver Time 0

Production quantity - 300 aircraft,  
including RDT&E

## Fuel Breakdown for Hypothetical Mission (Pounds)

Segment	Tilt Rotor		L/C Fan		Deflected Slipstream		Jet Flap		Fan-in-Wing	
	60	120	60	120	60	120	60	120	60	120
A - B	2,187	3,854	5,323	12,114	1,553	2,807	4,929	9,292	6,616	11,990
B - C	687	1,205	2,244	5,209	371	681	1,846	3,562	2,414	4,445
C - D	1,576	2,764	4,050	9,280	927	1,677	3,512	6,683	4,702	8,544
D - E	1,550	2,730	3,943	9,111	916	1,661	3,448	6,594	4,483	8,238
E - F	572	1,014	2,034	4,706	305	560	1,598	3,053	2,071	3,791
F - A	539	955	1,972	4,570	301	546	1,527	2,918	1,977	3,620

Note: Aircraft are final parametric designs and not final point designs.

Figure 55  
VTOL TERMINAL CONCEPT

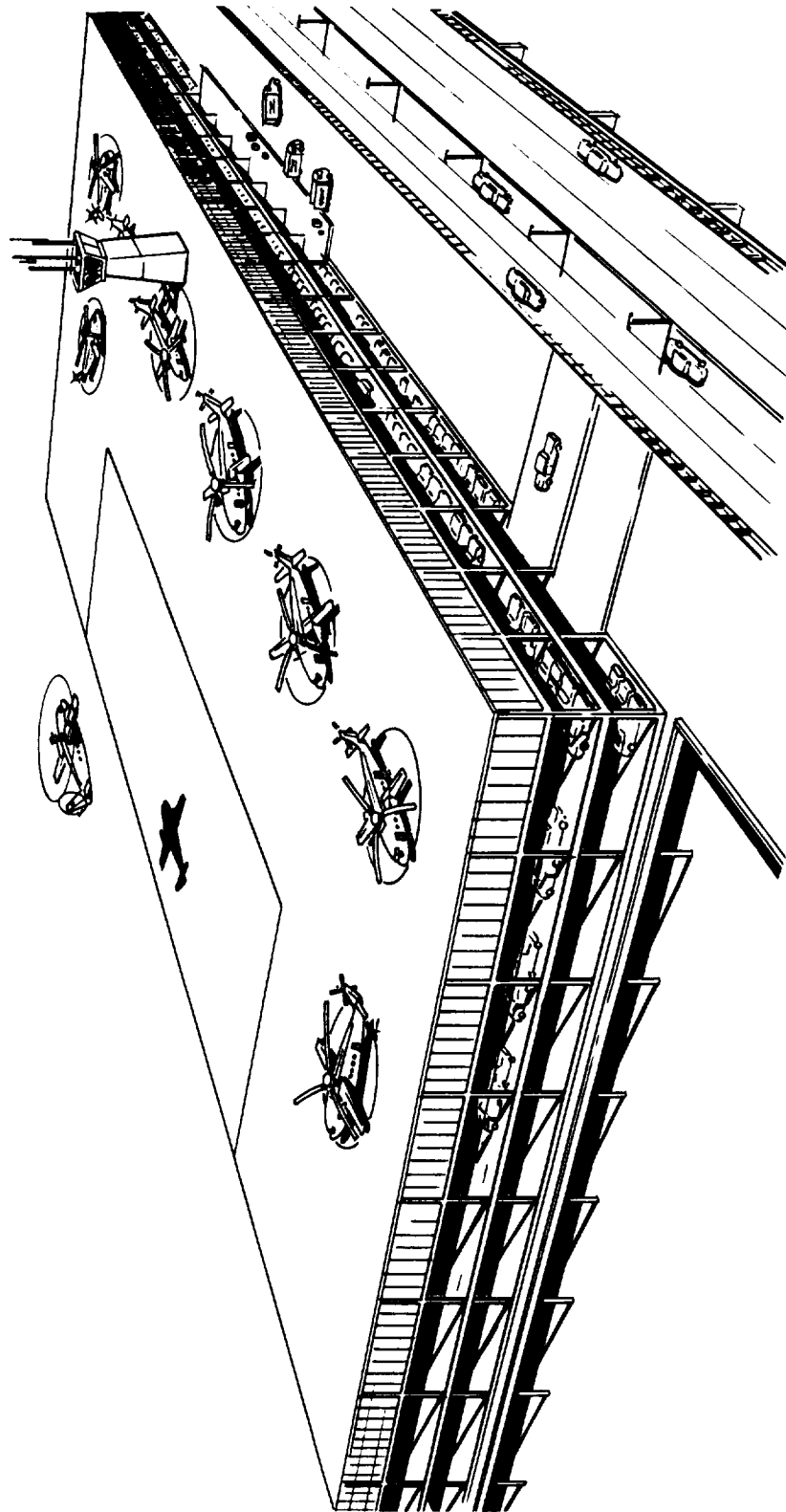


Figure 56  
VTOL CORRIDOR CONCEPT

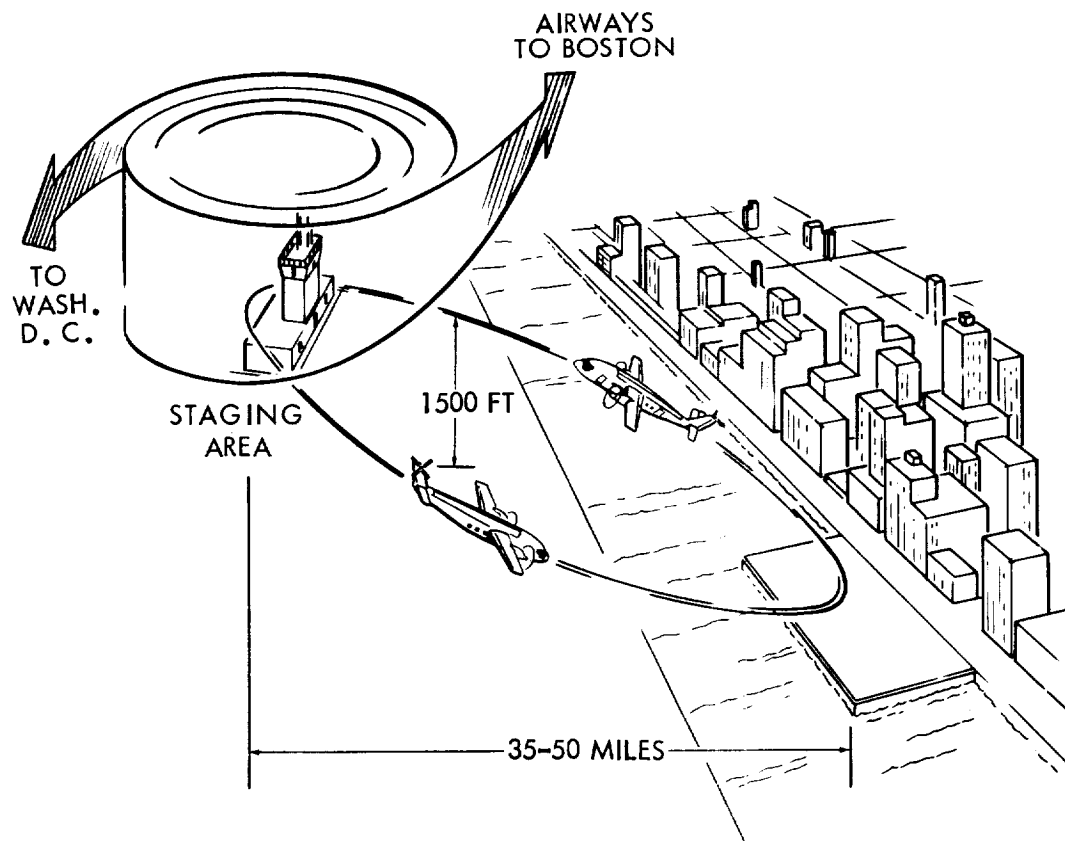


Figure 57

COMPARISON OF PEAK NOISE LEVELS  
MAX. STATIC THRUST - S.L. STD. DAY

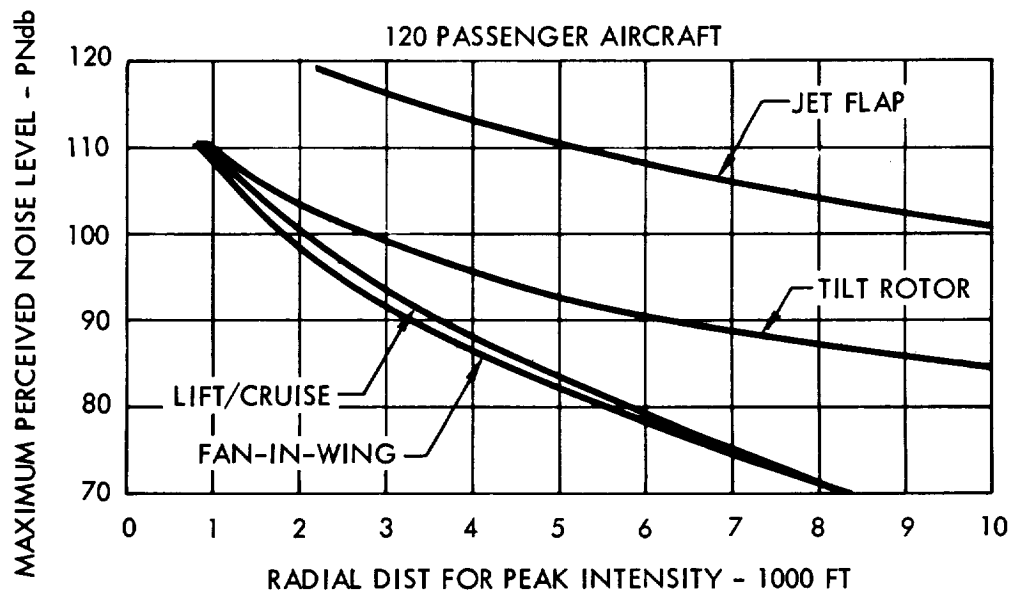
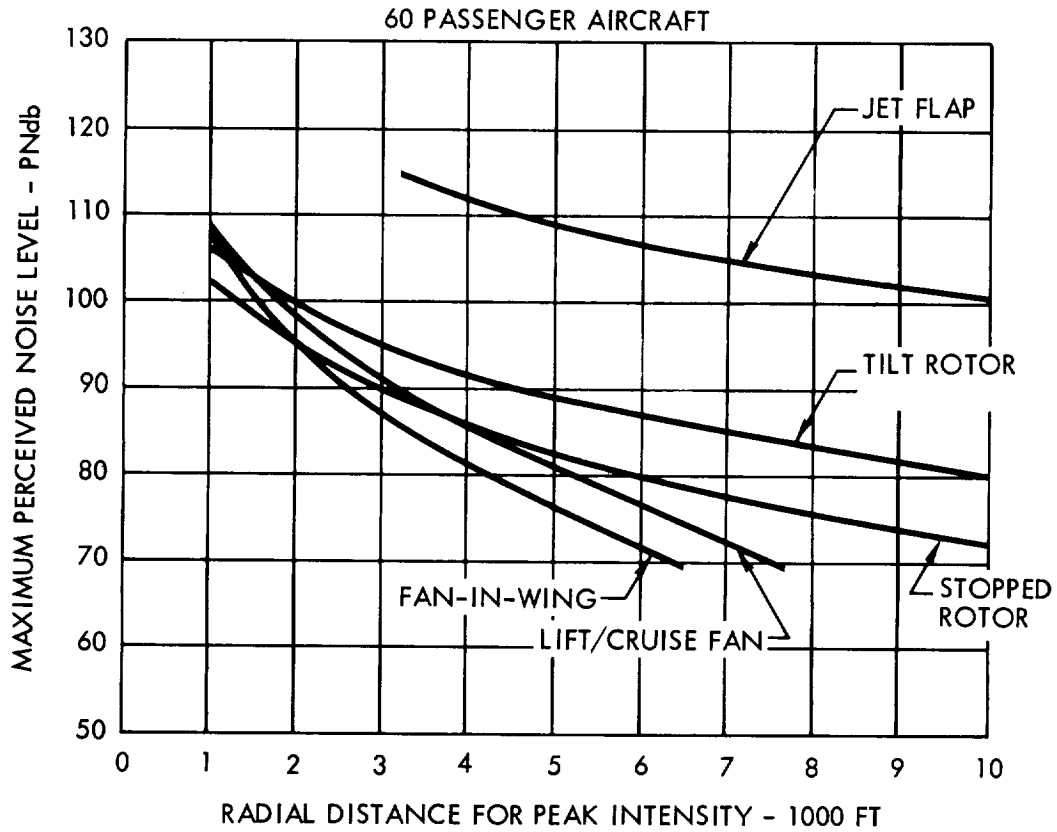


Figure 58

LIFT FAN NOISE LEVEL  
120-PASSENGER LIFT/CRUISE FAN VTOL

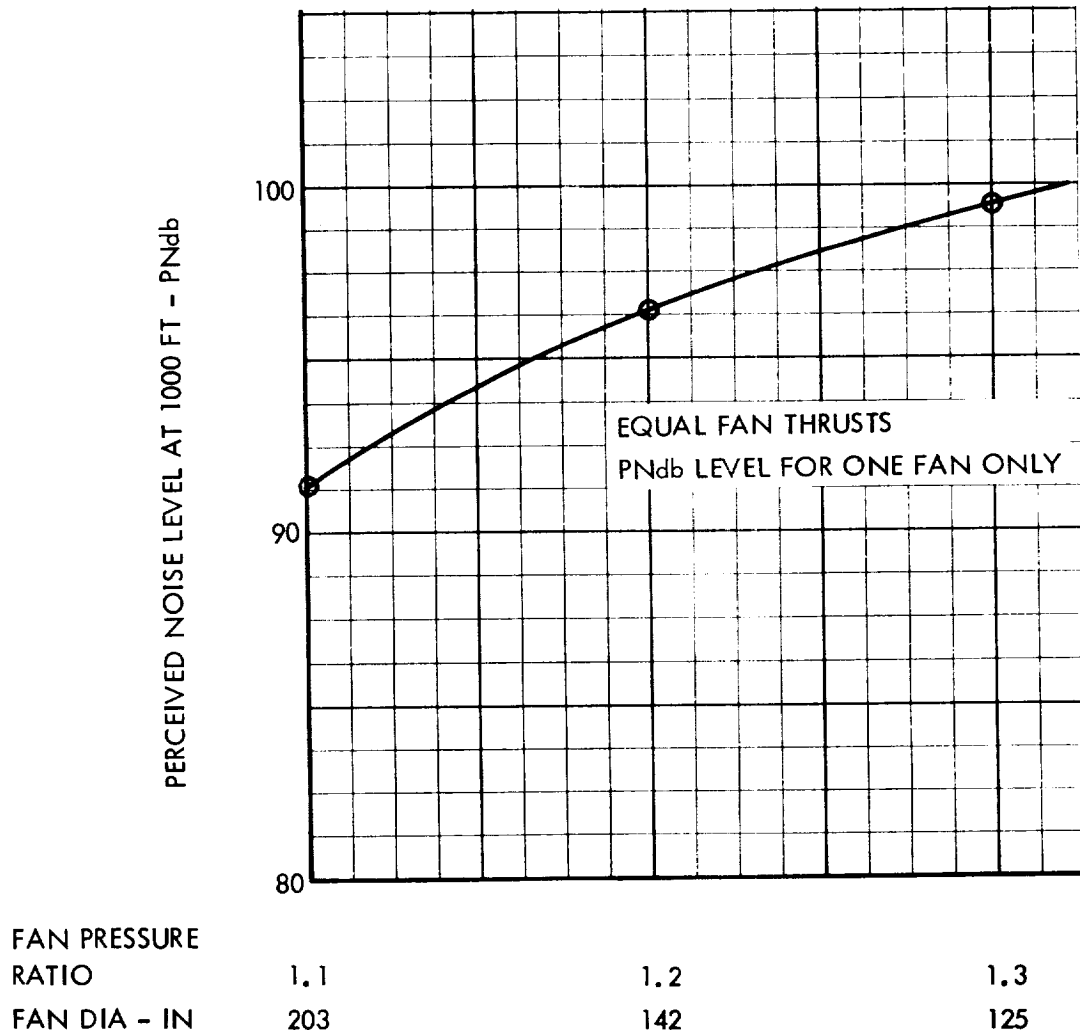


Figure 59

# SECTION SOUNDPROOFING WEIGHT REQUIREMENTS

120-PASSENGER JET FLAP  
TAKEOFF POWER AT BRAKE RELEASE

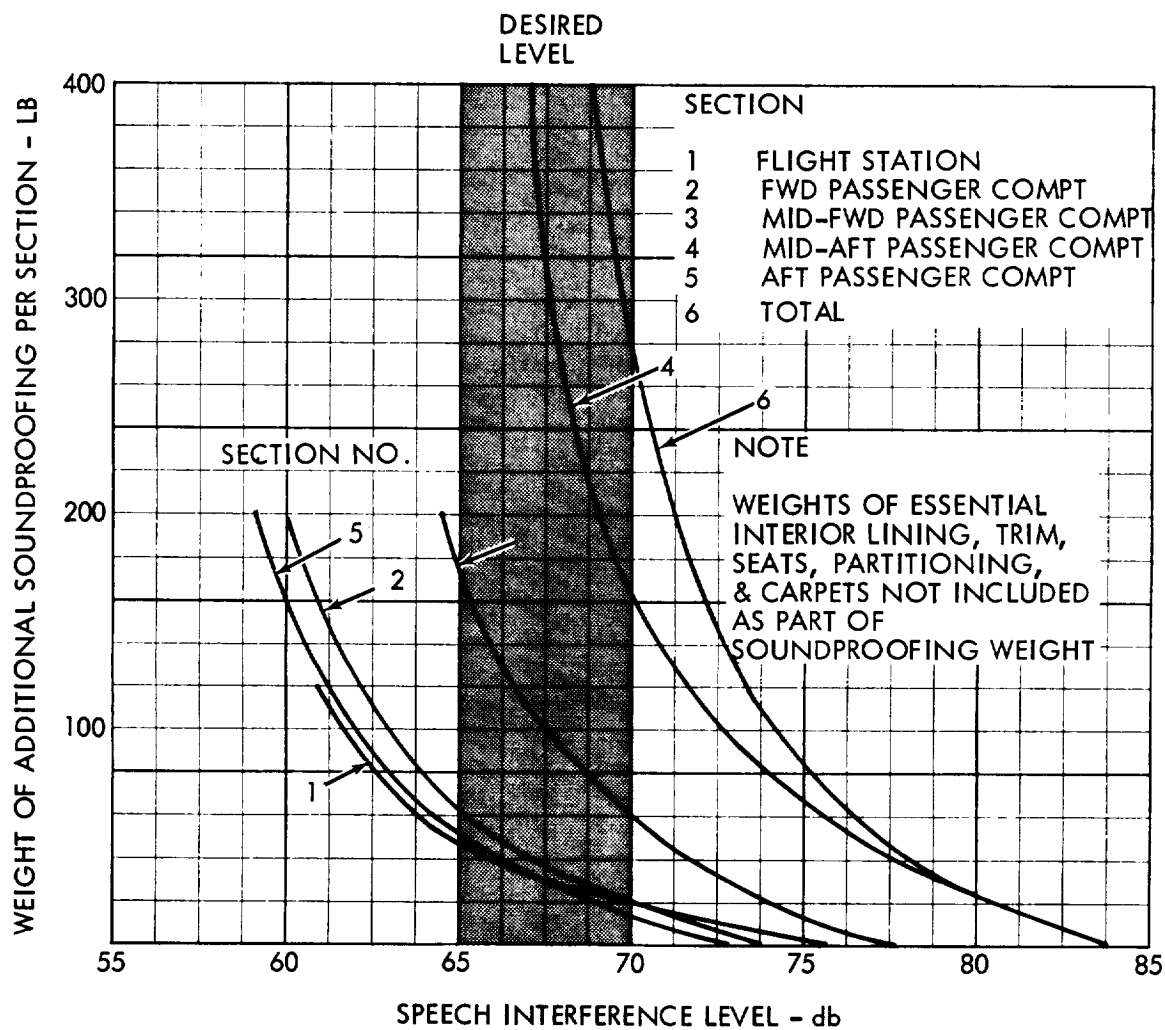


Figure 60  
COMPARISON OF STOL AIRCRAFT

	2000-FT JET FLAP		1000-FT FAN-IN-WING		2000-FT DEFLECTED SLIPSTREAM	
	60	120	60	120	60	120
NUMBER OF PASSENGERS						
$W_G$ (pounds)	63,200	120,000	67,900	124,000	46,900	86,400
$V_{Block}$ (mph)	424	425	440	444	281	279
D.O.C. (cents/seat mile)	2.26	1.77	2.67	2.04	1.96	1.47
FAIL SAFETY	10		9		10	
SERVICE/MAINTENANCE	9		8		10	
TAKE-OFF NOISE	7		9		10	
DEVELOPMENT RISK	9		8		10	
PREFERENCE	SECOND		SECOND		FIRST	

Figure 61  
COMPARISON OF VTOL AIRCRAFT

	LIFT/CRUISE FAN		TILT ROTOR		STOPPED ROTOR	
NUMBER OF PASSENGERS	60	120	60	120	60	120
$W_G$ (pounds)	71,800	141,600	65,000	123,500	71,000	134,000
$V_{Block}$ (mph)	409	409	341	344	359	365
D.O.C. (cents/seat mile)	2.87	2.36	2.67	2.01	2.65	2.03
FAIL SAFETY	8		9		10	
SERVICE/MAINTENANCE	7		10		9	
TAKE-OFF NOISE	8		9		10	
DEVELOPMENT RISK	9		9		10	
PREFERENCE	THIRD		SECOND		FIRST	



## APPENDIX A

### STUDY GUIDELINES

A summary of the guidelines established by the NASA to assure that all vehicles are designed on a common basis is presented in this appendix. Additional ground rules and invariants necessary to fully define the design constraints are discussed under the Parametric Study Section of this report.

#### All vehicles. -

- Range of 500 non-stop statute miles for all vehicles. (Additionally, V/STOL vehicles to be sized for a 50 statute mile stage with maximum payload for VTOL modes and 500 statute mile stage with maximum payload for STOL operation.
- Fuel reserve sufficient for a 30 minute hold at 5000 feet altitude plus fuel required to complete a go-around in an aborted landing.
- Landing weight equal to takeoff weight to permit operation over very short stage lengths.
- Maximum cruise speed compatible with optimum D.O.C., 300 knot minimum cruise speed preferred.
- Payload at 200 pounds per passenger including baggage plus an additional revenue cargo payload of 10 percent of passenger payload.
- Indiscriminate seating of at least half passenger payload (second half)
- Minimum of five abreast seating with 20-inch seat width and 32-inch seat spacing.
- Three crew members for 60 passenger aircraft and four crew members for 120 passenger versions.
- Load factors and fuselage pressurization in accordance with FAR part 25 and part 29.
- Aircraft design based on 1965-1970 technology using only power plants which can be made commercially available by 1970.
- Safety equivalent to that of existing multi-engine transports; that is the capability to maintain flight or to land under IFR conditions after sudden loss of one engine at any time.
- Takeoff and landing performance based on 86°F sea level day.

STOL operation. - The takeoff speed shall be at least 1.15 times the power on stall speed with the critical engine failed.

Takeoff performance over a 35-foot obstacle based on a FAA balanced field length and with the most critical engine failed.

Landing performance at takeoff gross weight, over a 50-foot obstacle based on a maximum deceleration of 0.5 g's and average braking coefficient of 0.4.

Landing field length equal to landing distance divided by 0.6.

Approach speed margin sufficient to maintain control when encountering a 10 knot sharp edged vertical or horizontal gust with the most critical engine failed.

Stability and Control. - Satisfactory landing characteristics (pilot ratings of 3.5 or better) during all portions of the flight.

Simultaneous use of controls should allow 100 percent of design control power on one axis and 50 percent on other axes. With the most critical engine failed simultaneous control power should not be less than 20 percent in pitch, 20 percent in yaw, and 50 percent in roll of the operative design values.

No limit on descent airspeed prior to reaching the specified basic approach pattern.

Current ceiling and visibility requirements on IFR approach are 100-ft ceiling and 1/4-mile visibility.

VTOL control power and thrust margins

60 passenger:

- 100% single axis control power at hover,  $\text{rad/sec}^2$ 
  - Roll - 1.2
  - Pitch - 0.6
  - Yaw - 0.5

- All engines operating and aircraft trimmed

$T/W = 1.15$ , no control

$T/W = 1.05$  (50% roll acceleration  
(20% pitch acceleration  
(20% yaw acceleration

$T/W = 1.05$ , 100% single axis control

- Most Critical Engine failed and aircraft trimmed

$T/W = 1.05$ , no control

$T/W = 1.00$  (50% roll acceleration  
(20% pitch acceleration  
(20% yaw acceleration

120 Passengers:

Thrust margins same as 60 passenger: control powers reduced to 80 percent of 60 passenger vehicle requirements.

#### STOL control power

60 passenger:

- 100% single axis control power,  $\text{rad/sec}^2$

Roll - 0.45

Pitch - 0.40

Yaw - 0.20

- All engines operative

100% control about any axis and 50% about remaining two axes.

120 passengers:

All control powers are 80 percent of 60 passenger vehicle requirements.



## APPENDIX B

### WEIGHT STANDARDIZATION

During the Lockheed study, component weights were estimated from statistical data and from structural studies of unique structural aspects of each concept. The Naval Air System Command, Weight Control Branch evaluated the weights of the 60-passenger VTOL Tilt Rotor, 1000-ft STOL Fan-in-Wing, 2000-ft STOL Deflected Slipstream, 2000-ft STOL Jet Flap, and VTOL Lift/Cruise Fan. The evaluation consisted of NASC deriving component weight estimates based on their methods.

The NASC weight estimates differed from Lockheed's in some areas and revised gross weights were developed by Lockheed based on the NASC weight estimates. After the weights were revised the direct operating costs for various stage lengths were calculated. These D.O.C.'s were then compared with the D.O.C.'s previously derived to describe a band of D.O.C versus stage length for the described weight sensitivity.

When the five concepts were scaled up in gross weight, the wing loading, thrust/weight, and disc loading were held constant so that vehicle performance did not change significantly with respect to cruise altitude and cruise speed for the relatively small weight changes. The fuel required for the 500-mile mission was determined from data developed on fuel required versus gross weight with the above parameters held constant.

Figure B-1 summarizes the results of the weight standardization. Lockheed's gross weights and NASC gross weights are shown along with the percent weight change. The resultant direct operating costs and percent D.O.C. changes are also shown for the five concepts. The maximum deviation of the gross weights is 9.5%, however, for vehicle comparison purposes the maximum deviation is 3.0%. The maximum deviation of the direct operating costs is 7.6% and for vehicle comparison purposes the maximum deviation is 3.2%.

The direct operating cost versus stage length for the weight standardization is tabulated in Figure B-2. The final parametric aircraft are also shown so that a wider range of gross weights may be examined and their effects on D.O.C. evaluated.

Figure B-1

WEIGHT STANDARDIZATION - NASC AND LOCKHEED'S GROSS WEIGHTS AND RESULTANT DIRECT  
OPERATING COSTS - 60 PASSENGERS, 500 MILE STAGE LENGTH

Aircraft Type	Lockheed Gross Weight (lb)	NASC Gross Weight (lb)	Percent Weight Change	Lockheed Weight-DOC ¢/Seat Mile	NASC Weight-DOC ¢/Seat Mile	Percent DOC Change
Tilt Rotor- VTOL	65,000	71,200	+9.5	2.67	2.83	+6.0
Fan In Wing- 1000-ft STOL	67,900	73,400	+8.1	2.67	2.81	+5.2
Deflected Slipstream- 2000-ft STOL	46,900	50,500	+7.7	1.96	2.11	+7.6
Jet Flap- 2000-ft STOL	63,200	67,300	+6.5	2.26	2.36	+4.4
Lift/Cruise Fan- VTOL	71,800	77,900	+8.5	2.87	3.03	+5.6

Figure B-2

WEIGHT STANDARDIZATION - DIRECT OPERATING COST VERSUS STAGE LENGTH  
 300 PRODUCTION UNITS - 2000 HOURS UTILIZATION - 60 AVAILABLE SEATS - DIRECT OPERATING  
 COSTS SHOWN IN CENTS PER SEAT MILE

Aircraft Type	Gross Weight (lb)	25 Mile Stage Length	50 Mile Stage Length	100 Mile Stage Length	200 Mile Stage Length	500 Mile Stage Length
Tilt Rotor Final Parametric Final Point Design NASC Weights	58,200	9.42	5.71	3.76	2.79	2.27
	65,000	11.08	6.71	4.42	3.28	2.67
	71,200	11.76	7.13	4.69	3.48	2.83
Lift/Cruise Fan Final Parametric Final Point Design NASC Weights	70,000	13.82	8.08	5.16	3.64	2.82
	71,800	14.06	8.22	5.25	3.70	2.87
	77,900	14.74	8.63	5.51	3.90	3.03
Deflected Slipstream Final Parametric Final Point Design NASC Weights	45,600	6.84	4.29	2.96	2.30	1.92
	46,900	6.98	4.38	3.02	2.35	1.96
	50,500	7.48	4.72	3.24	2.53	2.11
Jet Flap Final Parametric Final Point Design NASC Weights	59,500	10.56	6.32	4.06	2.92	2.18
	63,200	10.92	6.54	4.21	3.03	2.26
	67,300	11.28	6.79	4.38	3.17	2.36
Fan-In-Wing Final Parametric Final Point Design NASC Weights	63,700	12.42	7.42	4.84	3.44	2.54
	67,900	13.05	7.80	5.09	3.62	2.67
	73,400	13.67	8.17	5.34	3.80	2.81



## APPENDIX C

### NOISE SENSITIVITY ANALYSIS

During the Short Haul Transport study it became evident that noise is a major problem for all short-haul aircraft. Therefore, a study was conducted to assess the sensitivity of far-field perceived noise to parametric changes in aircraft design in terms of weight, speed and D.O.C.

In order to evaluate the sensitivity of far-field noise to aircraft design changes, the propeller and/or rotor tip speed was varied on the Deflected Slipstream, Tilt Rotor, and Stopped Rotor concepts. Aircraft were designed for tip speeds of 700, 800, and 900 fps. For the Fan-in-Wing and Jet Flap concepts, far-field noise was determined as a function of T/W ratio.

The physical characteristics of the 60 passenger aircraft selected for noise sensitivity analysis are tabulated in Figure C-1. The Deflected Slipstream aircraft are 2000-ft STOL vehicles. Therefore W/S and T/W ratios are held constant as propeller tip speed is varied. The tip speed variation affects the propeller activity factor selection and the engine power requirements. The Jet Flap and Fan-in-Wing aircraft were designed for two different field lengths of 1000-ft and 2000-ft. This results in significant changes in gross weight, engine power, T/W, and tail areas. The Tilt Rotor and Stopped Rotor aircraft are VTOL vehicles. The tip speed variation affects figure of merit or engine power requirements, rotor blade characteristics, and gearbox requirements. These variations affect the vehicle gross weight.

The 500-statute-mile range performance for the aircraft selected for noise sensitivity analysis are shown in Figure C-2.

The effects on noise of changes in tip speed and thrust-to-weight ratio were evaluated at two locations:

1. The point of maximum perceived noise level (PNL) on a 500-foot-radius circle centered at the aircraft, operating at maximum power, just prior to brake release or lift-off.
2. A point 5,000 feet from brake release (or lift-off) as the aircraft flies overhead (maximum PNL).

The flight paths used for VTOL aircraft were take-off without a vertical climb segment, typical of airport operation. These flight paths are shown in Figure C-3 which also shows the flight paths with 400-foot vertical climb segments.

The 400-foot climb segment would have a small effect on D.O.C. (about 2% for a 500 mile stage length), small increase in fuel and gross weight, and some reduction in noise as shown in Figure C-9.

The VTOL aircraft are still in the helicopter mode and have not transitioned to the cruise configuration. The take-off profiles for the STOL aircraft shown in Figure C-3 were determined by the power setting (take-off power with no power cutback).

The total noise spectrum from which the PNL was calculated was obtained by energy summation of the contributing sources. The sound pressure levels (SPL) for the various sources were obtained in the following manner:

1. Propeller and rotor rotational noise: measured data with adjustments based on Gutin theory (Reference 1).
2. Rotor vortex noise: calculated by the method of Reference 1, based on Yudin's theory.
3. Turboshift engine noise: adjusted measured data.
4. Jet noise: SAE method (Reference 2).
5. Fan noise: method in Reference 3.

The results of this study are shown in Figures C-4 through C-9. Each vehicle is discussed in the following sections.

#### Deflected Slipstream

The effect of propeller tip speed on block speed, gross weight, D.O.C., and PNdB (5000-ft from brake release) is shown in Figure C-4. The block speed or cruise speed increases as tip speed is reduced since the engine power increases to hold the static T/W ratio constant as the tip speed is reduced. Since the propeller activity factor selection consists of a trade-off between static and cruise efficiency, the engines are slightly oversized to reduce the activity factor and provide better cruise performance for the lower propeller tip speeds. The aircraft gross weight increases as tip speed is reduced due to the increase in engine size, and propeller activity factor. The increase in engine size increases engine, nacelle, accessories, shafting, gearboxes, and usable fuel weights. The increase in propeller activity factor increases the propeller weight and a decrease in tip speed increases the propeller gearbox weight. The D.O.C. decreases as tip speed is reduced because the higher block speed more than offsets the adverse effect of increased gross weight. Reductions in tip speed result in increased power required for the 2000-foot takeoff distance. This increase in power offsets the noise reduction expected from reductions in tip speed which results in very minor differences in PNL.

### Jet Flap

The effect of static thrust-to-weight ratio on block speed, gross weight, D.O.C., and PNdB is shown in Figure C-5. The block speed decreases as T/W ratio increases due to the two facts: (1) both of the aircraft cruise at a Mach number in the drag rise and (2) as the T/W ratio is increased to that required for 1000-ft STOL, the wing thickness must be increased to incorporate the flap duct system. This increased thickness lowers the wing critical Mach number causing the aircraft to encounter the drag rise at a lower speed. The gross weight increases as the T/W ratio is increased because of the larger engines, larger empennage areas, and higher fuel weights. The larger engines cause higher nacelle, engine, accessories, and duct system weights. The D.O.C. increases as T/W ratio is increased due to the lower block speed, higher gross weight, and higher engine costs for the larger engines. The primary noise sources are the high-velocity, small-area multiple nozzles. The lower power of the 2000-foot STOL results in lower on-ground noise; however, the higher fly-over altitude of the 1000-foot STOL results in a reduced PNL for this vehicle at the 5000-foot location.

### Fan-in-Wing

The effect of static thrust-to-weight ratio on block speed, gross weight, D.O.C., and PNdB is shown in Figure C-6. The block speed increases slightly due to a increase in T/W ratio. The gross weight increases as T/W ratio increases due to larger engine and fan sizes, empennage areas, and fuel requirements. The D.O.C. increases as T/W ratio is increased since the increase in block speed does not offset the adverse effects of increased gross weight and higher engine cost due to increased engine size. The major noise source at close distances is the fan blade passage noise. The SPL of this source is essentially the same for both aircraft; thus, the on-ground PNL is the same for both aircraft. This high-frequency fan noise will be subject to rapid attenuation with increasing distance due to the effects of atmospheric absorption. This accounts for the sizable difference in PNL for the fly-over at the 5000-foot point (SPL differences are approximately 7 db due to spherical spreading and 4 db due to atmospheric absorption). These effects are greater as altitude increases.

### Tilt Rotor

The effect of rotor tip speed on block speed, gross weight, D.O.C., and PNdB is shown in Figure C-7. There is very little change in block speed as the tip speed is varied since figure of merit and propulsive efficiency changes tend to offset each other. The gross weight increases as tip speed is reduced due to rotor blade changes and an increase

in gearbox weights. The rotor blades require more planform area as tip speed is reduced. The D.O.C. increases as tip speed is reduced due to the increase in gross weight and decrease in block speed. Reduction of tip speed results in increased power required to overcome the associated increase in gross weight. However, changes in the rotor system along with the reduction in tip speed more than offset the increase in power resulting in a net noise reduction.

#### Stopped Rotor

The effect of rotor tip speed on block speed, gross weight, D.O.C., and PNdB is shown in Figure C-8. The block speed increases slightly as tip speed is reduced since the heavier gross weights require a constant T/W ratio and vehicle drag does not increase directly with gross weight. The gross weight increases as tip speed is reduced due to rotor blade changes and an increase in gearbox weights. The rotor blades require more planform area as tip speed is reduced. The D.O.C. increases as tip speed is reduced due to the increase in gross weight. The slight increase in block speed does not overcome this weight increase. Reductions in tip speed result in increased power required and consequently increased noise output. The 900- and 800-fps versions follow the expected pattern of increasing PNL with decreasing tip speed. However, the 700-fps version does not follow this pattern, the PNL for this version being lower than expected from the results for the 900- and 800-fps versions. This is due to one of the more intense harmonics of rotational noise being lowered to a subaudible frequency as a direct result of the reduction in tip speed.

#### Vehicle Comparison

The results of the noise sensitivity analysis are summarized in Figure C-9.

STOL Aircraft. - The jet-flap aircraft has the most severe on-ground and fly-over noise of all the STOL aircraft. The fan-in-wing is the next noisiest due to the high level, high frequency fan blade passage noise. At distances much greater than the 500 foot radial distance selected for the on-ground evaluation, the fan-in-wing could conceivably be the quietest due to the rapid attenuation of high frequencies by the atmosphere. The least noisy vehicle in this group is the deflected slipstream. The results of this study indicate that, for the ground rules used, parametric changes to the aircraft studied did not produce significant changes in vehicle noise. The differences in fly-over noise are due primarily to differences in altitude.

VTOL Aircraft. - The noise outputs from both the tilt rotor and stopped rotor vehicles are nearly identical. The tilt rotor aircraft is the only vehicle which benefits from

reductions in tip speed. The amount of increase in altitude for reductions in fly-over noise (as demonstrated by the noise levels at the 5000-foot point for the two different altitudes used) indicates that vertical climb capability of VTOL aircraft can be used to advantages as a noise abatement technique by increasing altitude prior to community fly-over. Thus, VTOL aircraft should be able to meet any reasonable community noise restrictions with the possible exception of "close-in" operational distances in heavily populated areas. Appropriate area zoning and VTOL landing site selection can minimize this latter problem. It has been noted previously that a vertical climb segment at take-off and landing will increase the D.O.C. about 2% for a 500 mile stage length.

Figure C-1A

## PHYSICAL CHARACTERISTICS OF SELECTED AIRCRAFT FOR NOISE SENSITIVITY ANALYSIS

AIRCRAFT TYPE	NOISE MODEL	Wg (pounds)	AR	$\lambda$	t/c Root	t/c Tip	S (sq ft)	W/S (lb/sq ft)	b (feet)	$\Lambda c/4$ (degrees)
Deflected Slipstream (2000-ft STOL)	900 fps	46,900	6	.70	.15	.13	832	56	71	0
	800 fps	48,000	6	.70	.15	.13	857	56	72	0
	700 fps	49,300	6	.70	.15	.13	876	56	73	0
Jet Flap	1000-ft STOL	77,700	8	.40	.15	.13	971	80	88	25
	2000-ft STOL	63,200	8	.40	.13	.10	843	75	82	25
Fan-In-Wing	1000-ft STOL	67,900	6	.44	.13	.11	1069	64	80	25
	2000-ft STOL	59,000	6	.44	.13	.11	880	67	73	25
Tilt Rotor (VTOL)	900 fps	65,000	6	.60	.16	.14	835	78	71	0
	800 fps	67,900	6	.60	.16	.14	890	76	73	0
	700 fps	76,400	6	.60	.16	.14	1067	72	80	0
Stopped Rotor (VTOL)	900 fps	71,000	6	.60	.14	.12	592	120	60	0
	800 fps	75,000	6	.60	.14	.12	625	120	61	0
	700 fps	85,700	6	.60	.14	.12	714	120	65	0

Figure C-1B

PHYSICAL CHARACTERISTICS OF SELECTED AIRCRAFT FOR NOISE  
SENSITIVITY ANALYSIS

AIRCRAFT TYPE	NOISE MODEL	P <sub>D</sub> (feet)	W/A (lb/sq ft)	T/W	T/Eng. (pounds)	SHP/Eng.	F <sub>D</sub> (lift) (inches)	F <sub>D</sub> (cruise) (inches)	S <sub>H</sub> (sq ft)	S <sub>V</sub> (sq ft)
Deflected Slipstream (2000-ft STOL)	900 fps	14	-	.47	-	1275	-	-	237	211
	800 fps	14	-	.47	-	1390	-	-	237	211
	700 fps	14	-	.47	-	1610	-	-	237	211
Jet Flap	1000-ft STOL	-	-	.60	12,640	-	-	-	216	249
	2000-ft STOL	-	-	.40	6,800	-	-	-	125	172
Fan-In-Wing	1000-ft STOL	-	-	.35	6,488	-	55	-	330	293
	2000-ft STOL	-	-	.28	4,370	-	49	-	243	247
Tilt Rotor (VTOL)	900 fps	56	13	-	-	3840	-	-	237	122
	800 fps	58	13	-	-	3980	-	-	248	127
	700 fps	66	11.2	-	-	4700	-	-	278	143
Stopped Rotor (VTOL)	900 fps	16 <sup>a</sup>	13	-	-	4350	-	-	63	104
	800 fps	16 <sup>b</sup>	13	-	-	4650	-	-	67	110
	700 fps	16 <sup>c</sup>	13.6	-	-	5690	-	-	76	126

<sup>a</sup> Rotor Diameter 83.4 ft

<sup>b</sup> Rotor Diameter 85.6 ft

<sup>c</sup> Rotor Diameter 89.5 ft

Figure C-2  
500 STATUTE MILE RANGE PERFORMANCE FOR SELECTED AIRCRAFT  
FOR NOISE SENSITIVITY ANALYSIS

AIRCRAFT TYPE	NOISE MODEL	W <sub>f</sub> (pounds)	W <sub>f</sub> Block (pounds)	V <sub>Cruise</sub> (knots)	V <sub>Block</sub> (mph)	η <sub>p</sub> (cruise)	Fig. of Merit	H <sub>p</sub> Cruise (feet)	D.O.C. c/seat mi.
Deflected Slipstream (2000-ft STOL)	900 fps	3220	2408	283	281	.92	-	15,280	1.96
	800 fps	3510	2680	298	311	.90	-	15,000	1.90
	700 fps	3780	2920	335	323	.89	-	15,000	1.86
Jet Flap	1000-ft STOL	14,440	10,510	478	406	-	-	31,000	2.90
	2000-ft STOL	9875	7294	483	424	-	-	31,000	2.26
Fan-In-Wing	1000-ft STOL	13,980	10,640	493	440	-	-	30,000	2.67
	2000-ft STOL	10,700	7880	475	419	-	-	30,000	2.48
Tilt Rotor (VTOL)	900 fps	6400	4350	363	341	.765	.69	25,000	2.67
	800 fps	6680	4540	363	341	.78	.71	25,000	2.70
	700 fps	7500	5100	365	335	.79	.72	25,000	3.09
Stopped Rotor (VTOL)	900 fps	7940	6260	400	359	.85	.69	20,000	2.65
	800 fps	8400	6620	405	361	.85	.71	20,000	2.70
	700 fps	9600	7560	437	370	.85	.72	20,000	3.12

Figure C-3

TAKEOFF AND CLIMB PROFILES

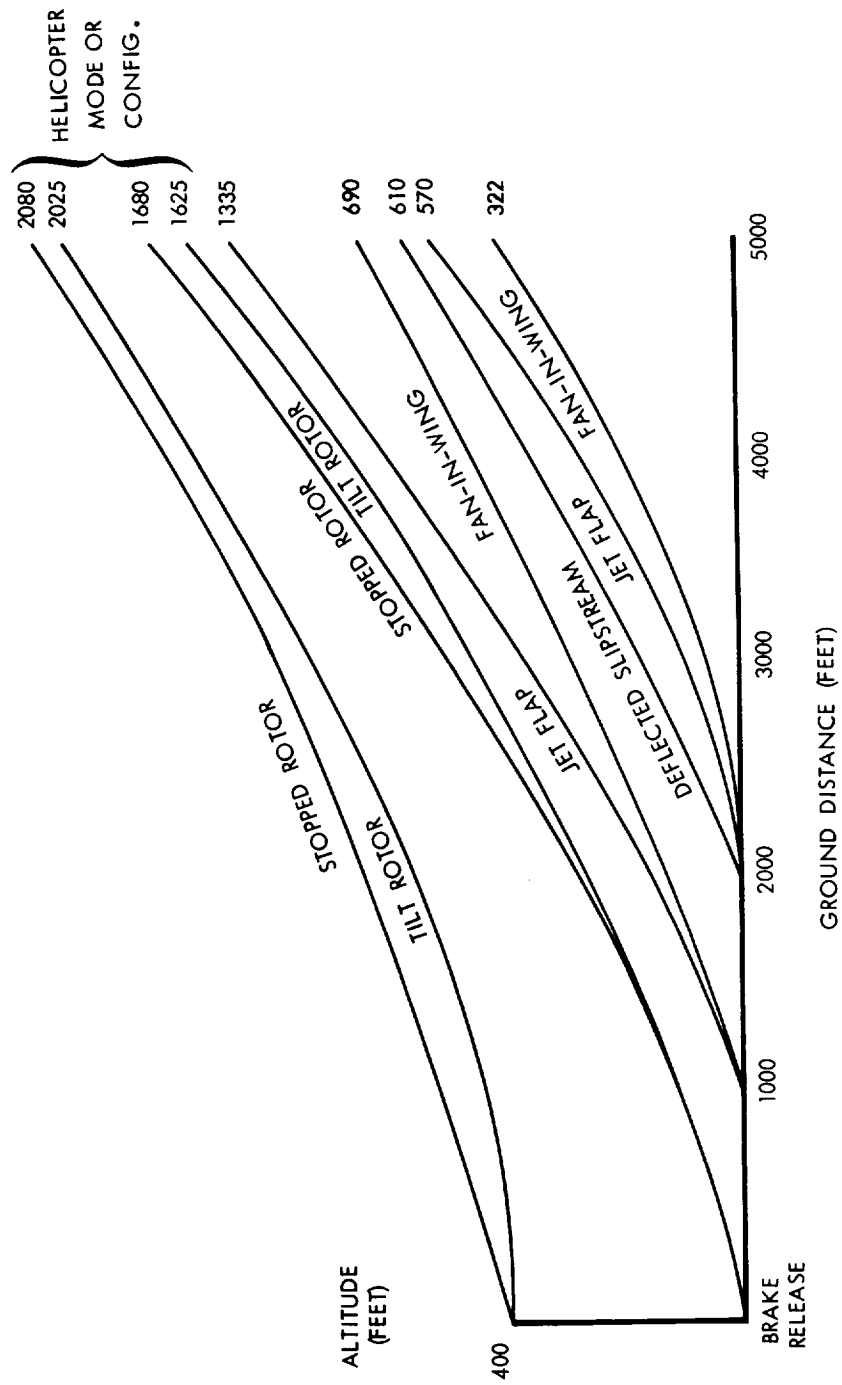


Figure C-4

DEFLECTED SLIPSTREAM  
SENSITIVITY OF CHARACTERISTICS TO PROPELLER TIP SPEED

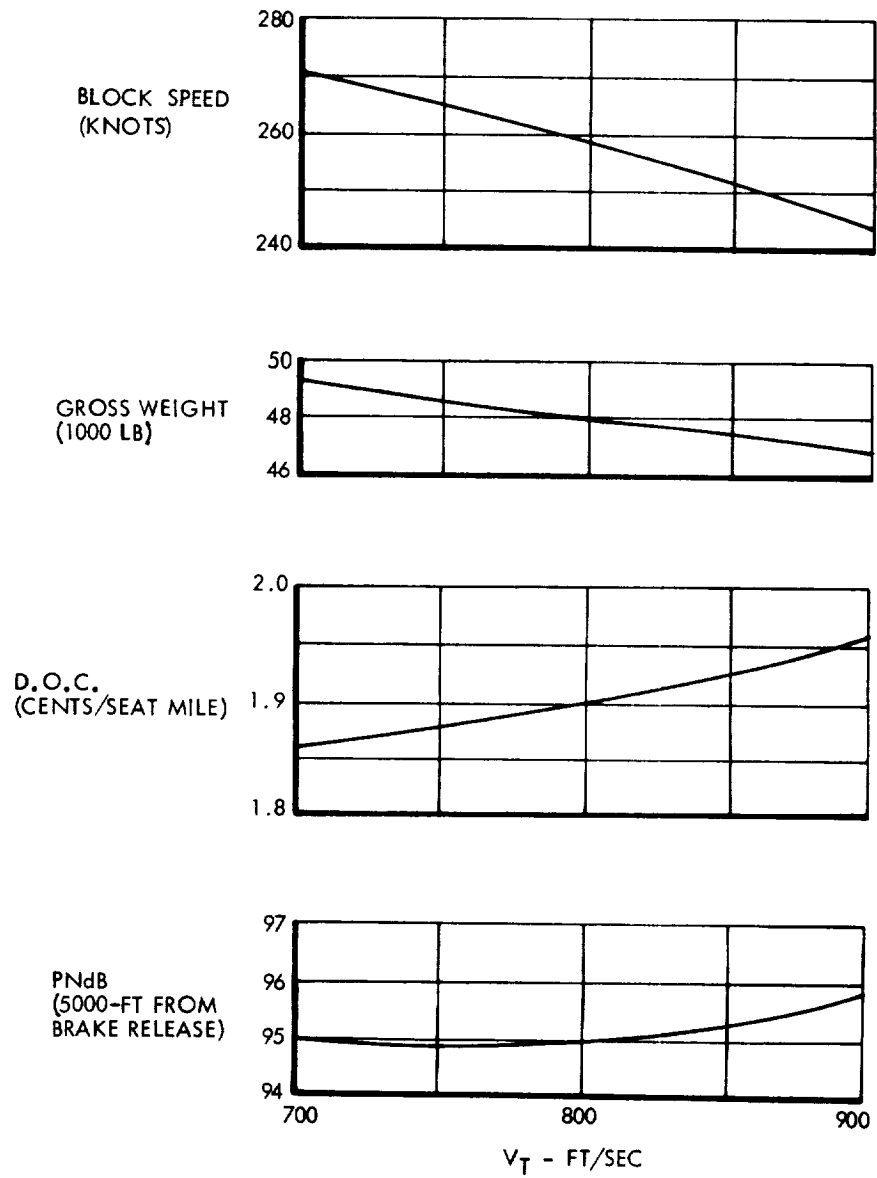


Figure C-5  
JET FLAP  
SENSITIVITY OF CHARACTERISTICS TO  $T/W_{\text{STATIC}}$

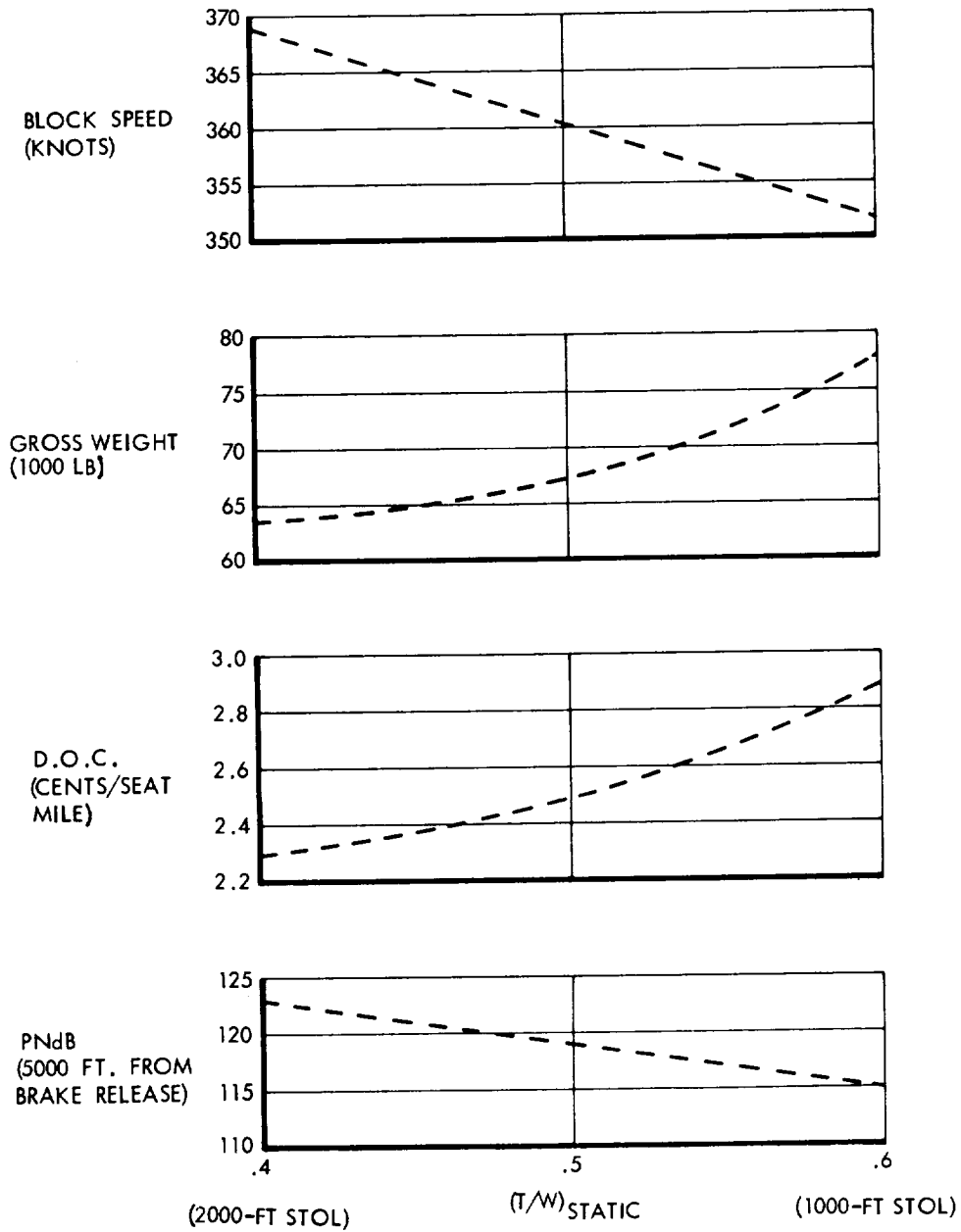


Figure C-6

FAN-IN-WING  
SENSITIVITY OF CHARACTERISTICS TO  $(T/W)_{\text{STATIC}}$

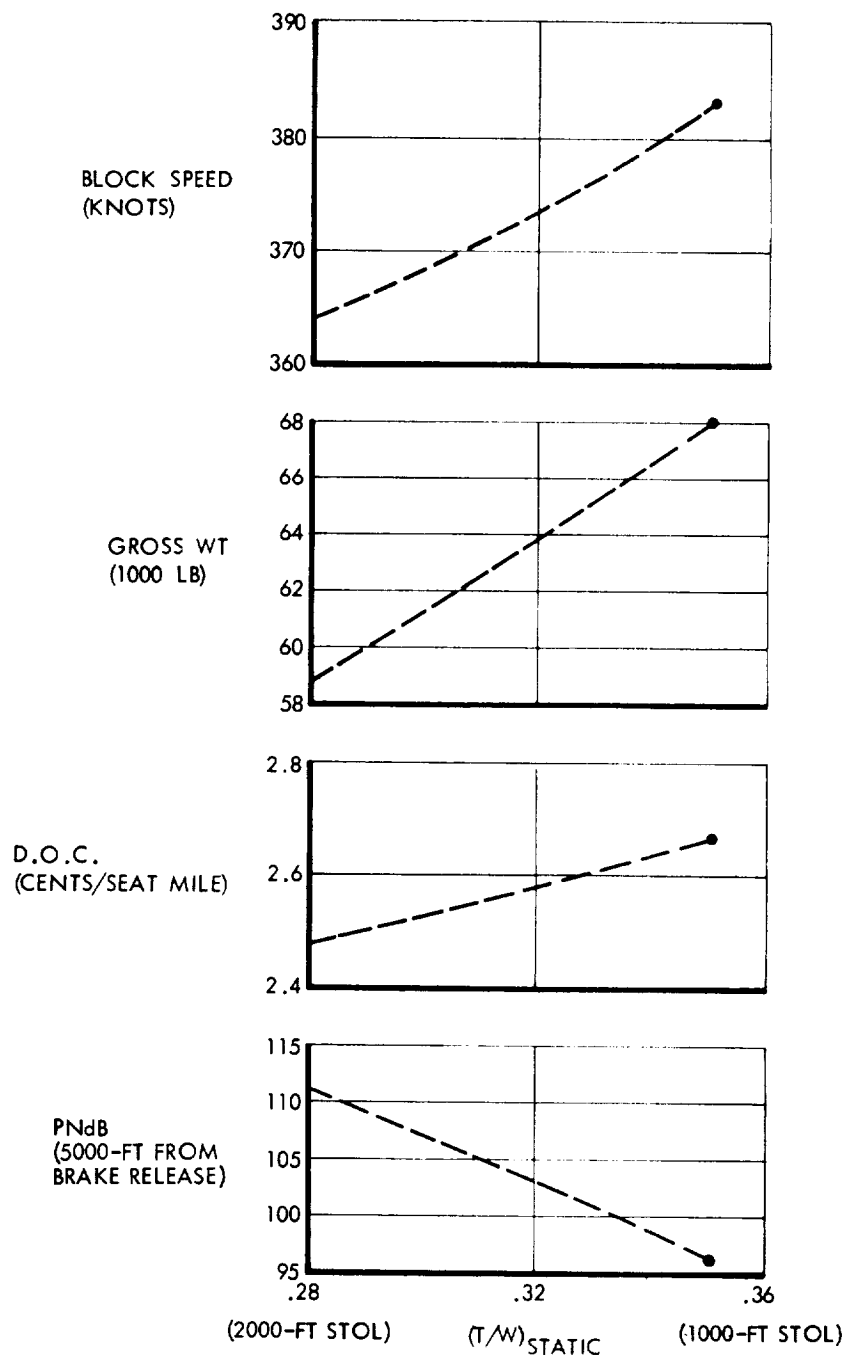


Figure C-7  
TILT ROTOR  
SENSITIVITY OF CHARACTERISTICS TO ROTOR TIP SPEED

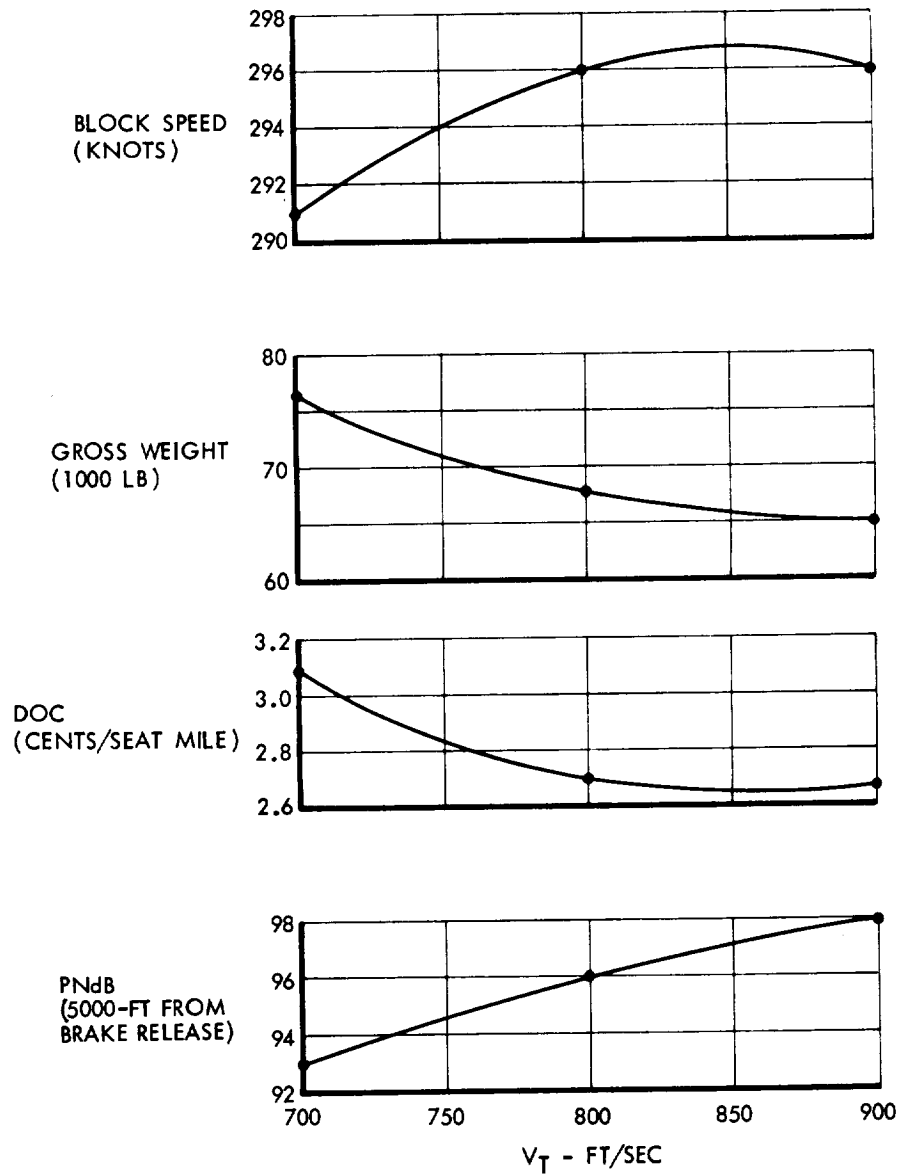


Figure C-8

STOPPED ROTOR  
SENSITIVITY OF CHARACTERISTICS TO ROTOR TIP SPEED

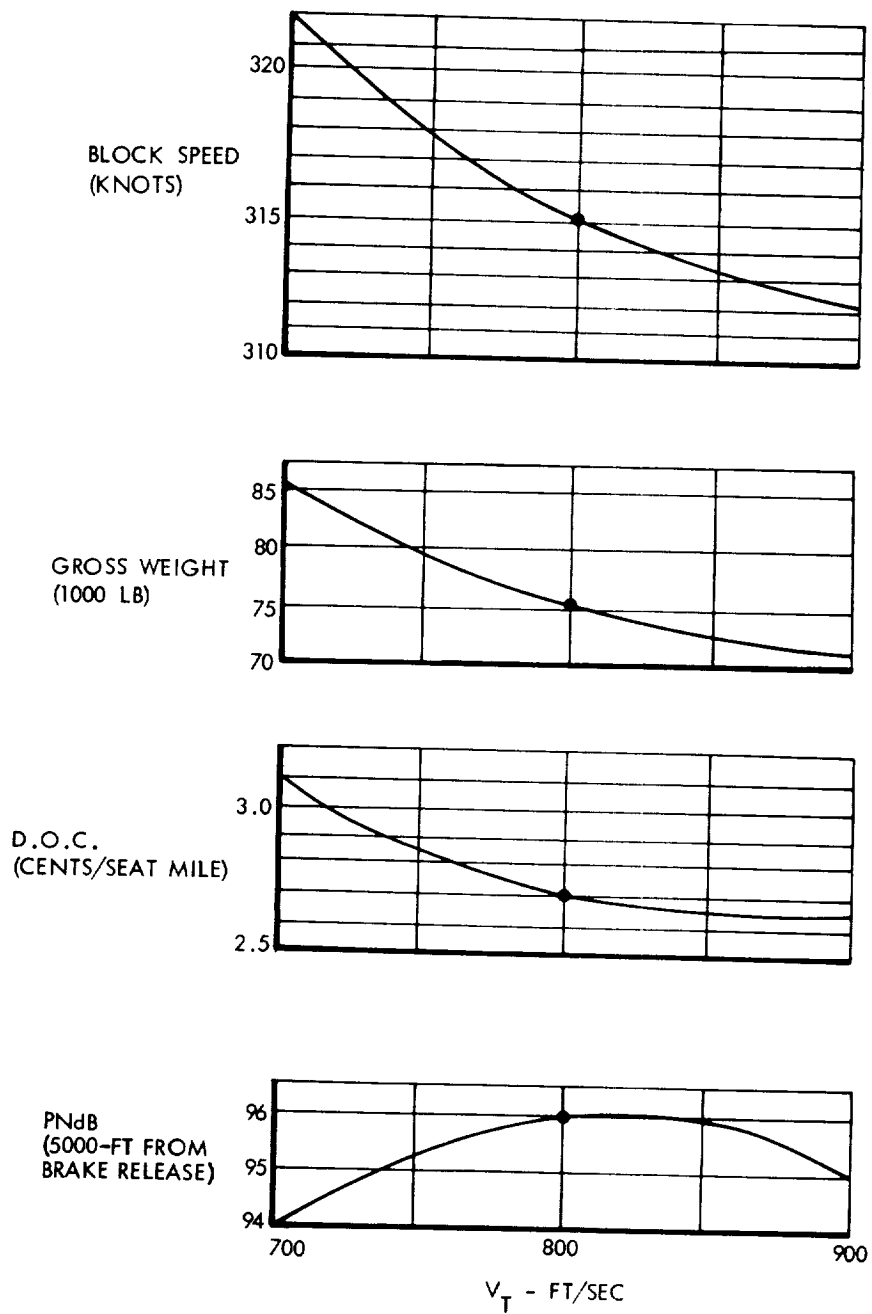


Figure C-9

## RESULTS OF THE NOISE SENSITIVITY ANALYSIS

AIRCRAFT TYPE	MODEL	GROSS WEIGHT (lb)	D.O.C. (cents/seat mile)	BLOCK SPEED (knots)	CRUISE SPEED (knots)	PERCEIVED NOISE LEVEL (PNdB) AT BRAKE RELEASE	PERCEIVED NOISE LEVEL (PNdB) 5000 ft FROM B.R.	ALTITUDE 5000 ft FROM B.R. (feet)
Deflected Slipstream	900 fps	46,900	1.96	244	283	100	96	610
	800 fps	48,000	1.90	259	311	99	95	610
	700 fps	49,300	1.857	271	335	99	95	610
Jet Flap	1000-ft STOL	77,700	2.9	353	478	130	115	1335
	2000-ft STOL	63,200	2.3	369	483	128	123	570
Fan-In-Wing	VTOL	DOES NOT APPLY TO THIS STUDY						
	1000-ft STOL	67,900	2.67	383	493	105	99	690
	2000-ft STOL	59,000	2.475	364	475	105	111	322
Tilt Rotor	900 fps	65,000	2.67	296	363	111	96/98*	2025/1625*
	800 fps	67,900	2.70	296	363	109	93/96*	2020/1620*
	700 fps	76,400	3.09	291	365	108	90/93*	2000/1600*
Stopped Rotor Prop	900 fps	71,000	2.65	312	400	109	92/95*	2080/1680*
	800 fps	75,000	2.70	315	410	110	93/96*	2090/1690*
	700 fps	85,700	3.12	322	437	109	91/94*	2190/1790*

\* Double numbers refer to altitudes for the two different takeoff profiles (see text). The lower PNL refers to the higher altitude.

NOTE: All perceived noise levels rounded to nearest whole PNdB.



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